AERONAUTICS

SEVENTH ANNUAL REPORT

OF THE

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

1921

INCLUDING TECHNICAL REPORTS
NOS. 111 TO 132

WASHINGTON
GOVERNMENT PRINTING OFFICE
1923

LETTER OF SUBMITTAL.

To the Congress of the United States:

In compliance with the provisions of the act of March 3, 1915, establishing the National Advisory Committee for Aeronautics, I transmit herewith the seventh annual report of the committee for the fiscal year ended June 30, 1921.

I think there can be no doubt that the development of aviation will become of great importance for the purposes of commerce, as well as for national defense. While the material progress in aircraft has been remarkable, the use has not as yet been extensively developed in America. This has been due, in the main, to lack of wise and necessary legislation. Aviation is destined to make great strides, and I believe that America, its birthplace, can and should be foremost in its development.

I therefore urge upon the Congress the advisability of giving heed to the recommendations of the committee, the first and most important of which is that a bureau be established in the Department of Commerce for the regulation and development of air navigation.

WARREN G. HARDING.

THE WHITE HOUSE,
December 7, 1921.

LETTER OF TRANSMITTAL.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
Washington, D. C., November 28, 1921.

THE PRESIDENT:

In compliance with the provisions of the act of Congress approved March 3, 1915 (naval appropriation act, Public No. 273, 63d Cong.), I have the honor to transmit herewith the Seventh Annual Report of the National Advisory Committee for Aeronautics, including a statement of its expenditures for the fiscal year ended June 30, 1921.

The progress in scientific research during the past year is described in the reports of the technical subcommittees and is exemplified by the technical reports (Nos. 111 to 132, inclusive) which have been published during the past year, summaries of which are contained in this report. The relative value of scientific research in the development of aeronautics is greater now than ever before, as the development of aviation in the absence of necessary legislation and without the stimulus of war is slow, and it would be more so were it not for the continuous prosecution of organized scientific research.

The problem of developing the uses of aircraft requires the Federal regulation of air navigation and the establishment and regulation of transcontinental airways, including the necessary airdromes and weather report stations.

Attention is especially invited to the Summary of General Recommendations of the committee, preceding the body of the report, and setting forth what, in the judgment of the committee, are the most important steps to be taken for the advancement of aeronautics. The committee lays special emphasis at this time on the advisability of the Federal Government giving aid in this great and promising field of development and urges that the most important single measure in the general policy outlined by the committee is the enactment of legislation establishing a bureau in the Department of Commerce for the regulation and development of air navigation.

Respectfully submitted.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
CHARLES D. WALCOTT, *Chairman*.

SUMMARY OF GENERAL RECOMMENDATIONS.

The more important general recommendations of the National Advisory Committee for Aeronautics are summarized as follows:

LEGISLATION FOR THE DEVELOPMENT OF AVIATION.

The most urgent need for the successful development of aviation at the present time, either for military or civil purposes, is the enactment of legislation providing for the Federal regulation of air navigation, and the establishment of airways and airdromes under Federal regulation. The Federal regulation should include the licensing of aviators, aircraft, and airdromes; the airways should consist of chains of landing fields providing supply and repair facilities and including the necessary meteorological stations, observations, and reports. If the Federal Government will establish and regulate transcontinental airways, as recommended, the committee is confident that air lines for the transportation of passengers or goods will be rapidly established by private enterprise in all parts of the country. The first national airways, however, should be carefully planned to serve military as well as civil needs. The committee reiterates its former recommendations as to the manner of accomplishing the desired results, and urgently recommends the establishment by law of a Bureau of Air Navigation in the Department of Commerce.

EXTENSION OF AEROLOGICAL SERVICE.

The committee emphasizes the importance of extending aerological service (under the Weather Bureau) along airways as established, and recommends that adequate provision of law be made for this service, which is so indispensable to the success and safety of air navigation.

POLICY TO SUSTAIN THE INDUSTRY.

Whatever may have been the faults or the shortcomings of the aircraft industry during or since the war, the fact remains that there must be an aircraft industry, and that it should be kept in such a condition as to be able to expand promptly and properly to meet increased demand in case of emergency. The Government, as the principal consumer, is directly concerned in the matter, and should formulate a policy which would be effective to sustain and stabilize the aeronautical industry and encourage the development of new and improved types of aircraft. In this respect the committee invites attention to the recommendation contained in its special report submitted to the President on April 9, 1921, published as House Document 17, and again recommends the adoption of a policy which, while safeguarding the interests of the Government, will tend to sustain and stabilize the industry.

IMPORTANCE OF MILITARY AVIATION.

Aviation is indispensable to the Army and to the Navy in warfare; and its relative importance will continue to increase. Other branches of the military services are comparatively well developed, whereas aviation is still in the early stages of its development. The demand for greatly reduced expenditures in the military and naval services should not apply to the air services. The committee recommends that liberal provision be made for the Army and Navy Air Services, not only that provision be made for the maintenance and training of personnel, but also that the funds be adequate to insure the fullest development of aviation for military and naval purposes.

SCIENTIFIC RESEARCH.

Substantial progress in aeronautical development, whether for military or commercial purposes, must be based upon the application to the problems of flight of scientific principles and the results of research. The exact prescribed function of the National Advisory Committee for Aeronautics is the prosecution and coordination of scientific research, and, while encouragement may be taken from the progress made, greater provision for the continuous prosecution of research on a larger scale is strongly recommended by the committee.

THE AIR MAIL SERVICE.

The Air Mail Service has demonstrated that airplanes can be utilized with certain advantages in carrying the mails. And it has done more than this, despite the handicap of using, military types of aircraft, poorly adapted to its work or to any civil or commercial purpose, in demonstrating that commercial aviation for the transportation of passengers or goods is feasible. There are several causes which are delaying the development of civil aviation, such as the lack of airways, landing fields, aerological service, and aircraft properly designed for commercial uses. The Air Mail Service stands out as a pioneer agency, overcoming these handicaps and blazing the way, so to speak, for the practical development of commercial aviation. As a permanent proposition, however, the Post Office Department, as its functions are now conceived, should no more operate directly a special air mail service than it should operate a special railroad mail service; but until such time as the necessary aids to commercial aviation have been established it will be next to impossible for any private corporation to operate under contract an air mail service in competition with the railroads. The National Advisory Committee for Aeronautics therefore recommends that provision be made for the continuation of the Air Mail Service under the Post Office Department.

HELIUM AND AIRSHIPS.

The United States has a virtual monopoly of the known sources of supply of helium, and these are limited. Experiments have been conducted by the Bureau of Mines with a view to the development of methods of production and storage, but as yet the problem of storage in large quantities has not been satisfactorily solved. Because the known supply is limited, because it is escaping into the atmosphere at an estimated rate sufficient to fill four large airships weekly, and because of the tremendously increased value and safety which the use of helium would give to airships, particularly in warfare, it is, in the opinion of the National Advisory Committee for Aeronautics, the very essence of wisdom and prudence to provide for the conservation of large reserves through the acquisition and sealing by the Government of the best helium-producing fields. Attention now being given to the development of types of airships to realize fully the advantages which the use of helium would afford should be continued. Such development would give America advantages, for purposes either of war or commerce, with which no other nation could successfully compete.

CONTENTS.

TECHNICAL REPORTS.[1]

[1] Technical Reports, numbers 1 to 110, published with previous Annual Reports.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

2722 NAVY BUILDING, WASHINGTON, D. C.

CHARLES D. WALCOTT, Sc.D., *Chairman*,
    Secretary, Smithsonian Institution, Washington, D. C.
S. W. STRATTON, Sc.D., *Secretary*,
    Director, Bureau of Standards, Washington, D. C.
JOSEPH S. AMES, Ph.D., *Chairman Executive Committee*,
    Director, Physical Laboratory, Johns Hopkins University, Baltimore, Md.
THURMAN H. BANE, Major, United States Army,
    Chief, Engineering Division, Air Service, Dayton, Ohio.
WILLIAM F. DURAND, Ph.D.,
    Professor of Mechanical Engineering, Leland Stanford Junior University, California.
JOHN F. HAYFORD, C. E.,
    Director, College of Engineering, Northwestern University, Evanston, Ill.
CHARLES F. MARVIN, M. E.,
    Chief, United States Weather Bureau, Washington, D. C.
WILLIAM A. MOFFETT, Rear Admiral, United States Navy,
    Chief, Bureau of Aeronautics, Navy Department, Washington, D. C.
MASON M. PATRICK, Major General, United States Army,
    Chief of Air Service, War Department, Washington, D. C.
MICHAEL I. PUPIN, Ph. D.,
    Professor of Electro-Mechanics, Columbia University, New York City.
D. W. TAYLOR, Rear Admiral, United States Navy,
    Chief Constructor, Navy, Washington, D. C.
ORVILLE WRIGHT, B. S.,
    Dayton, Ohio.

EXECUTIVE COMMITTEE.

JOSEPH S. AMES, *Chairman*.
S. W. STRATTON, *Secretary*.

THURMAN H. BANE,
JOHN F. HAYFORD,
CHARLES F. MARVIN,
WILLIAM A. MOFFETT,
MASON M. PATRICK,
D. W. TAYLOR,
CHARLES D. WALCOTT.

SEVENTH ANNUAL REPORT

OF THE

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

Washington, D. C., November 28, 1921.

To the Congress:

In accordance with the provision of the act of Congress approved March 3, 1915, establishing the National Advisory Committee for Aeronautics, the committee submits herewith its seventh annual report. In this report the committee has described its activities during the past year, the technical progress in the study of scientific problems relating to aeronautics, the assistance rendered by the committee in the formulation of a policy regarding the Federal regulation of air navigation, the coordination of research work in general, the examination of aeronautical inventions, and the collection, analysis, and distribution of scientific and technical data. This report also contains a statement of expenditures, estimates for the fiscal year 1923, and recommendations as to the present requirements of aviation.

FUNCTIONS OF THE COMMITTEE.

The National Advisory Committee for Aeronautics was established by act of Congress, approved March 3, 1915. The organic act charges the committee with the supervision and direction of the scientific study of the problems of flight with a view to their practical solution, the determination of problems which should be experimentally attacked, their investigation and application to practical questions of aeronautics. The act also authorizes the committee to direct and conduct research and experimentation in aeronautics in such laboratory or laboratories in whole or in part as may be placed under its direction.

Supplementing the prescribed duties of the committee, its broad general functions may be stated as follows:

First. Under the law the committee holds itself at the service of any department or agency of the Government interested in aeronautics, for the furnishing of information or assistance in regard to scientific or technical matters relating to aeronautics, and in particular for the investigation and study of problems in this field with a view to their practical solution.

Second. The committee may also exercise its functions for any individual, firm, association, or corporation within the United States, provided that such individual, firm, association, or corporation defray the actual cost involved.

Third. The committee institutes research, investigation, and study of problems which, in the judgment of its members or of the members of its various subcommittees, are needful and timely for the advance of the science and art of aeronautics in its various branches.

Fourth. The committee keeps itself advised of the progress made in research and experimental work in aeronautics in all parts of the world, particularly in England, France, Italy, Germany, Austria, and Canada.

Fifth. The information thus gathered is brought to the attention of the various subcommittees for consideration in connection with the preparation of programs for research and experimental work in this country. This information is also made available promptly to the military and naval air services and other branches of the Government, and such as is not confidential is immediately released to university laboratories and aircraft manufacturers interested in the study of specific problems, and also to the public.

Sixth. The committee holds itself at the service of the President, the Congress, and the executive departments of the Government for the consideration of special problems which may be referred to it, such as organization of governmental activities in aeronautics, recommendations as to proper action under the Convention for the Regulation of International Air Navigation, questions of policy regarding the regulation and development of civil aviation, advanced education in aeronautical engineering, etc.

ORGANIZATION OF THE COMMITTEE.

The committee has 12 members, appointed by the President. The law provides that the personnel of the committee shall consist of two members from the War Department, from the office in charge of military aeronautics; two members from the Navy Department, from the office in charge of naval aeronautics; a representative each of the Smithsonian Institution, of the United States Weather Bureau, and of the United States Bureau of Standards; and not more than five additional persons acquainted with the needs of aeronautical science, either civil or military, or skilled in aeronautical engineering or its allied sciences. All members as such serve without compensation.

During the past year Rear Admiral William A. Moffett, Chief of the Bureau of Aeronautics in the Navy Department, was appointed by the President to membership on the committee to succeed Capt. T. T. Craven. The President has also appointed to membership on the committee Maj. Gen. Mason M. Patrick, who succeeded Maj. Gen. Charles T. Menoher as Chief of the Air Service of the Army.

The full committee meets twice a year, the annual meeting being held in October and the semiannual meeting in April. The present report includes the activities of the committee between the annual meeting held on October 7, 1920, and that held on October 6, 1921.

The present organization of the committee is as follows:

Charles D. Walcott, Sc. D., chairman.
S. W. Stratton, Sc. D., secretary.
Joseph S. Ames, Ph. D.
Maj. Thurman H. Bane, United States Army.
William F. Durand, Ph. D.
John F. Hayford, C. E.
Charles F. Marvin, M. E.
Rear Admiral William A. Moffett, Unites States Navy.
Maj. Gen. Mason M. Patrick, United States Army.
Michael I. Pupin, Ph. D.
Rear Admiral D W. Taylor, United States Navy.
Orville Wright, B. S.

THE EXECUTIVE COMMITTEE.

For carrying out the work of the Advisory Committee the regulations provide for the election annually of an executive committee, to consist of seven members, and to include further any member of the Advisory Committee not otherwise a member of the executive committee but resident in or near Washington and giving his time wholly or chiefly to the special work of the committee. The present organization of the executive committee is as follows:

Joseph S. Ames, Ph. D., chairman.
S. W. Stratton, Sc. D., secretary.
Maj. Thurman H. Bane, United States Army.
John F. Hayford, C. E.
Charles F. Marvin, M. E.
Rear Admiral William A. Moffett, United States Navy.
Maj. Gen. Mason M. Patrick, United States Army.
Rear Admiral D. W. Taylor, United States Navy.
Charles D. Walcott, Sc. D.

The executive committee, in accordance with the general instructions of the Advisory Committee, exercises the functions prescribed by law for the whole committee, administers the affairs of the committee, and exercises general supervision over all its activities. The executive committee held regular monthly meetings throughout the year, and in addition held five special meetings, on the following dates: October 7, 1920; January 27, April 4, April 8, and June 30, 1921.

The executive committee has organized the necessary clerical and technical staffs for handling the work of the committee proper. General responsibility for the execution of the programs and policies approved by the executive committee is vested in the executive officer, Mr. George W. Lewis. In the subdivision of general duties he has immediate charge of the scientific and technical work of the committee, being directly responsible to the chairman of the executive committee, Dr. Joseph S. Ames. The assistant secretary, Mr. John F. Victory, has charge of administration and personnel matters, property, and disbursements, under the direct control of the secretary of the committee, Dr. S. W. Stratton.

SUBCOMMITTEES.

The executive committee has organized six standing subcommittees, divided into two classes, administrative and technical, as follows:

ADMINISTRATIVE.	TECHNICAL.
Personnel, buildings, and equipment.	Aerodynamics.
Publications and intelligence.	Power plants for aircraft.
Governmental relations.	Materials for aircraft.

The organization and work of the technical subcommittees are covered in the reports of those committees appearing in another part of this report. A statement of the organization and functions of the administrative subcommittees follows:

COMMITTEE ON PERSONNEL, BUILDINGS, AND EQUIPMENT.

FUNCTIONS.

1. To handle all matters relating to personnel, including the employment, promotion, discharge, and duties of all employees.
2. To consider questions referred to it and make recommendations regarding the initiation of projects concerning the erection or alteration of laboratories and the equipment of laboratories and offices.
3. To meet from time to time on the call of the chairman, and report its actions and recommendations to the executive committee.
4. To supervise such construction and equipment work as may be authorized by the executive committee.

ORGANIZATION.

Dr. Joseph S. Ames, chairman.
Dr. S. W. Stratton, vice chairman.
Prof. Charles F. Marvin.
J. F. Victory, secretary.

COMMITTEE ON PUBLICATIONS AND INTELLIGENCE.

FUNCTIONS.

1. The collection, classification, and diffusion of technical knowledge on the subject of aeronautics, including the results of research and experimental work done in all parts of the world.
2. The encouragement of the study of the subject of aeronautics in institutions of learning.
3. Supervision of the office of aeronautical intelligence.

4. Supervision of the committee's foreign office in Paris.

5. The collection and preparation for publication of the technical reports, technical notes, and annual report of the committee.

ORGANIZATION.

Dr. Joseph S. Ames, chairman.
Prof. Charles F. Marvin, vice chairman.
Miss M. M. Muller, secretary.

COMMITTEE ON GOVERNMENTAL RELATIONS.

FUNCTIONS.

1. Relations of the committee with executive departments and other branches of the Government.

2. Governmental relations with civil agencies.

ORGANIZATION.

Dr. Charles D. Walcott, chairman.
Dr. S. W. Stratton,
J. F. Victory, secretary.

AVIATION BOMBING TESTS.

The sinking of former German warships in the aviation bombing tests held off the capes of the Chesapeake in June and July, 1921, demonstrated that warships of all types are vulnerable to attack from the air, and that aircraft may be advantageously employed in the defense of our coasts and in engagements with enemy fleets on the high seas. Even in naval engagements on the high seas at such distances from shore that coast-defense aircraft could not participate, aircraft will be employed by the contending fleets. The Navy, therefore, should develop airplane carriers which must provide means for aircraft to take off and alight during an engagement. The Navy has developed a catapult launching device and is also experimenting with the deck-landing problem. It is essential, in the judgment of the committee, that Congress authorize the construction of specially designed airplane carriers.

FEDERAL REGULATION OF AIR NAVIGATION - AIR ROUTES TO COVER THE WHOLE UNITED STATES - COOPERATION AMONG GOVERNMENT DEPARTMENTS CONCERNED WITH AVIATION.

The committee renews its previous recommendations for the establishment of a bureau of air navigation in the Department of Commerce, for the Federal regulation and licensing of air navigation, and to aid generally in the development of commercial aviation. The committee is not unmindful of the legal sentiment that a constitutional amendment should first be adopted before such legislation is enacted, on the ground that effective regulation of air navigation as proposed would otherwise be unconstitutional as violating the rights of private property and encroaching upon the rights of the States. To postpone such legislation until a constitutional amendment can be proposed and ratified would have the effect of greatly retarding the development of commercial aviation, with no assurance that sufficient popular interest would ever be aroused to accomplish such an amendment. The committee is of the opinion that the most effective course to be followed for the development of aviation would be to first enact the legislation deemed necessary for the Federal regulation of air navigation and the encouragement of the development of civil aviation, and let the question of the constitutionality of such legislation be tested in due course. In the meantime, there would be development in civil and commercial aviation, and if eventually the legislation which made possible such development should be definitely determined to be unconstitutional there would then, in all probability, be sufficient public interest in the subject and popular demand to adopt an amendment to the Constitution.

President Harding, in his first address to Congress on April 12, 1921, stated that the recommendation of the committee to provide for Federal regulation of air navigation ought to have legislative approval. There is virtual unanimity in aeronautical circles that Congress should establish a bureau of air navigation in the Department of Commerce for the Federal regulation of air navigation, for the establishment of airways, and in general for the development of civil and commercial aviation in all parts of the country.

On April 1, 1921, the President wrote the following letter to the chairman of the committee:

THE WHITE HOUSE,
Washington, April 1, 1921.

Dr. CHARLES D. WALCOTT,
Chairman National Advisory Committee for Aeronautics,
2722 Navy Building, Washington, D. C.

DEAR DR. WALCOTT: It is desired that you immediately organize a subcommittee of the National Advisory Committee for Aeronautics, with representatives from the War, Navy, Post Office, and Commerce Departments, and civil life; that the subcommittee take up vigorously and fully the question of Federal regulation of air navigation, air routes to cover the whole United States, and cooperation among the various departments of the Government concerned with aviation, reporting—

(*a*) What can and should be done without further legislative action.

(*b*) What legislative action and appropriations are necessary to carry into effect the recommendations of the subcommittee.

Very truly, yours,

WARREN G. HARDING.

A special meeting of the executive committee was promptly called, at which the subcommittee was organized in accordance with the President's request. This subcommittee held meetings in Washington on April 5, 6, 7, and 8, 1921. Its report was approved at another special meeting of the executive committee, held on April 8, and transmitted to the President on April 9. The President transmitted the report to the Congress with the following letter:

To the Senate and House of Representatives:

I transmit herewith for the consideration of the Congress a special report of the National Advisory Committee for Aeronautics, prepared at my request and dealing with Federal regulation of air navigation, air routes to cover the whole United States, and cooperation among the various departments of the Government concerned with aviation.

The attention of the Congress is invited to the statement of general considerations on a national aviation policy, and to the committee's recommendations for legislative action, which have my approval.

WARREN G. HARDING.

THE WHITE HOUSE, *April 19, 1921.*

The special report of the committee referred to is as follows:

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
Washington, D. C., April 9, 1921.

The PRESIDENT,
The White House.

DEAR MR. PRESIDENT: In accordance with your letter of April 1, 1921, addressed to Dr. Charles D. Walcott, chairman of the National Advisory Committee for Aeronautics, this committee organized a special subcommittee on Federal regulation of air navigation, as follows:

War Department: Maj. Gen. C. T. Menoher, United States Army; Maj. W. G. Kilner, United States Army.

Navy Department: Rear Admiral D. W. Taylor, United States Navy; Commander Kenneth Whiting, United States Navy.

Post Office Department: Mr. E. C. Zoll, Mr. C. I. Stanton.

Department of Commerce: Dr. S. W. Stratton, Mr. E. T. Chamberlain.

Representatives from civil life: Mr. Sidney Waldon, Mr. F. H. Russell, Mr. Glenn L. Martin.

Dr. Charles D. Walcott, chairman.

Mr. J. F. Victory, secretary.

This subcommittee has taken up, as you directed, the question of Federal regulation of air navigation, air routes to cover the whole United States, and cooperation among the various departments of the Government concerned with aviation, and, in addition, the two questions specified in your letter:

"(*a*) What can and should be done without further legislative action.

"(*b*) What legislative action and appropriations are necessary to carry into effect the recommendations of the subcommittee."

The report of this subcommittee is as follows:

The following general considerations on a national aviation policy are recommended:

1. Aviation is inseparable from the national defense. It is necessary to the success of both the Army and the Navy. Each should have complete control of the character and operations of its own air service.

2. Aeronautics is a comparatively new science capable of such tremendous and rapid development that it is of vital importance, in time of peace, to make the greatest possible progress in the science itself. Everything should be done to stimulate invention and to encourage the practical use of aircraft of all kinds and of all the equipment and appliances necessary or incidental thereto.

3. It is considered impracticable in time of peace to maintain a large armed air force, but it is considered imperative that we maintain a sufficient nucleus of available personnel, including organized reserves, and of adequate equipment of the most modern type as a foundation upon which to build at the outbreak of war.

4. It is essential that commercial aviation be fostered and encouraged in harmony with the military and naval aviation policies and programs. The development of aviation as a whole will be made with the minimum of expense to the Government through the adoption of a wise and constructive policy for the upbuilding of commercial aviation.

5. The air mail service is an important initial step in the development of civil and commercial aviation. It must be maintained and extended as rapidly as possible, not only to carry the mails but to become a potential war reserve.

6. It is a pressing duty of the Federal Government to regulate air navigation; otherwise independent and conflicting legislation by the various States will be enacted and hamper the development of aviation. For this purpose a bureau of aeronautics should be established in the Department of Commerce, by legislation similar to the Kahn bill as modified. (See draft of bill taken from Sixth Annual Report of the National Advisory Committee for Aeronautics, Appendix A.)

7. Approved policies with respect to the encouragement and development of commercial aviation should be carried out by the Department of Commerce.

8. The Army Air Service should be continued as a coordinate combatant branch of the Army. Its existing organization should be used in cooperation with the Navy, Post Office, and other governmental agencies in the prompt establishment of national continental airways and in cooperation with the States and municipalities in the establishment of local airdromes, landing fields, and other necessary facilities.

9. The Naval Air Service and the control of naval activities in aeronautics should be centralized in a bureau of aeronautics in the Navy Department.

10. The continuous prosecution of scientific research in aeronautics is now provided for by the National Advisory Committee for Aeronautics, established by law in 1915, and broad questions of policy regarding the coordination of the activities of all governmental agencies concerned with aeronautics should be referred to that committee for consideration and recommendation.

11. The National Advisory Committee for Aeronautics should have authority to recommend to the heads of the departments concerned on questions of policy regarding the development of aviation, and to recommend to departmental heads desirable undertakings or developments in the field of aviation. To provide for the more effective discharge of these functions, the chief of the air mail service of the Post Office Department and the chief of the proposed Bureau of Aeronautics in the Department of Commerce should be members of the committee.

12. Under this policy, there would be an Army Air Service under the Secretary of War; a Naval Air Service under the Secretary of the Navy, with its activities centralized in a Bureau of Aeronautics in the Navy Department; an air mail service under the Postmaster General; a bureau of aeronautics for the regulation of air navigation, under the Secretary of Commerce, and for carrying out such policies as may be adopted for the encouragement and upbuilding of civil and commercial aviation; a National Advisory Committee for Aeronautics for the continuous prosecution of scientific research in aeronautics, and, in an advisory capacity, the coordination of all aeronautical activities of the Government.

Referring specifically to the detailed questions under the three headings, namely, (1) "Federal regulation of air navigation," (2) "Air routes to cover the whole United States," (3) "Cooperation among the various departments of the Government concerned with aviation," the committee reports as follows:

1. Federal Regulation of Air Navigation.

(*a*) Federal regulation of air navigation can not be accomplished under existing laws. Smuggling and other illegal uses of aircraft can be prevented in a measure.

(*b*) It is recommended that a bureau of aeronautics be established in the Department of Commerce (substantially along the lines of the Kahn bill as modified) for the regulation of air navigation and for carrying out such policies as may be adopted for the encouraging and upbuilding of civil and commercial aviation, and that an estimate of $200,000 be submitted for the fiscal year 1922.

2. Air Routes to Cover the Whole United States.

(*a*) The Post Office Department is specifically authorized to establish an air route between New York and San Francisco. There is some question as to whether existing laws permit it to establish other routes.

The Army has no specific authority of law to establish air routes, but has charted seven important mail airways as follows:

1. One route from Augusta, Me., to Camp Lewis, Wash.
2. One from Washington, D. C., to San Francisco, Calif.

3. One from Savannah, Ga., to San Diego, Calif.
4. One from Augusta, Me., to Miami, Fla.
5. One from Camp Lewis, Wash., to San Diego, Calif.
6. One from Laredo, Tex., to Fargo, N. Dak.
7. One from Chicago, Ill., to Baton Rouge, La.

(Chart, Appendix B, shows these routes.)

(*b*) In order to enable the Army to carry forward its program of air routes to cover the whole United States, it is recommended that an appropriation of $2,000,000 be made available during a period of two years.

Attention is drawn to "Necessary aerological service and estimate of costs," Appendix C. It is recommended that such portions of the appropriations asked for as are necessary to give aerological service on the approximately 4,000 miles of air mail routes now in commission be made available, and that the funds to cover additional stations along the national continental air routes to cover the whole United States be made available as fast as the need is indicated by the Army and the Post Office Department.

It is recommended that legislation be enacted which will definitely authorize the Post Office Department to establish air mail routes between Chicago, Minneapolis, and St. Paul, and between Chicago and St. Louis, and such other air mail routes as may be determined by the Postmaster General as the need for them arises, taking full advantage, wherever practicable, of existing or contemplated airways.

3. Cooperation Among the Various Departments of the Government Concerned with Aviation.

(*a*) Cooperation among the air services of the Army, Navy, and Post Office with Coast and Geodetic Survey, Bureau of Fisheries, Coast Guard, Weather Bureau, Geological Survey, and forest patrol service is being carried on with excellent results, as shown in Appendix D.

It is recommended that the President direct the National Advisory Committee for Aeronautics to appoint a subcommittee composed of representatives of the War, Navy, Post Office, and Commerce Departments, and two civilians representing the aircraft industry, who shall survey the engineering and production facilities of the aircraft industry and shall recommend a policy calculated to sustain and develop the industry to meet the needs of the Government.

(*b*) Attention is drawn to the memorandum on forest fire patrol, Appendix E. It is recommended that the funds ($217,151) and personnel asked for be made available for the purpose specified.

In summing up this report, permit me to emphasize the immediate need of legislation to provide for—

First. A naval air service under the Secretary of the Navy, with its activities centralized in a bureau of aeronautics in the Navy Department.

Second. A bureau of aeronautics under the Secretary of Commerce for the regulation of air navigation and the encouragement and upbuilding of civil and commercial aviation.

Third. The development of a system of national continental air routes to cover the whole United States and to include the meteorological service essential thereto.

Fourth. The extension of the air mail service.

Fifth. Making the chief of the air mail service and the chief of the proposed bureau of aeronautics of the Department of Commerce members of the National Advisory Committee for Aeronautics.

Respectfully submitted.

National Advisory Committee for Aeronautics.
C. D. Walcott, *Chairman.*

Appendixes.

A. Draft of modified Kahn bill.
B. Continental airways and approximate costs.
C. Necessary aerological service and estimate of costs.
D. Cooperation among the various departments of the Government concerned with aviation.
E. Cooperation of War and Agricultural Departments and operating cost of forest fire patrol.

Report of Subcommittee on Federal Regulation of Air Navigation, Etc., National Advisory Committee for Aeronautics.

Appendix A.

DRAFT OF MODIFIED KAHN BILL.

[Note.—The modified Kahn bill referred to is not here reproduced, having been previously printed in the committee's sixth annual report. The bill was introduced in the first session of the Sixty-seventh Congress by Representative Hicks of New York, and is now known as the Hicks bill (H. R. 271).]

REPORT OF SUBCOMMITTEE ON FEDERAL REGULATION OF AIR NAVIGATION, ETC., NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

APPENDIX B.

CONTINENTAL AIRWAYS AND APPROXIMATE COSTS.

[By Air Service of the Army.]

Seven important main airways have been charted, and by utilizing Government airdromes already existing these airways make the air net complete for the United States.

One route from the State of Maine to the State of Washington covers the following stations:

Augusta, Me., municipal.
Plattsburg, N. Y., Government, not Air Service.
Binghamton, N. Y., municipal.
Buffalo, N. Y., private.
Cleveland, Ohio, private.
Detroit, Mich., Air Service.
Bryan, Ohio, municipal.
Chicago, Ill., Government, not Air Service.
Winona, Minn., municipal.
St. Paul, Minn., Government, not Air Service.
Fargo, N. Dak., municipal.
Portal, N. Dak., municipal.
Miles City, Mont., Government, not Air Service.
Missoula, Mont., municipal.
Spokane, Wash., private.
Camp Lewis, Wash., Government, not Air Service.

One transcontinental route from Washington, D. C., to San Francisco, Calif.:

Bolling Field, Anacostia, D. C., Air Service.
Moundsville, W. Va., municipal.
Dayton, Ohio, Air Service.
Speedway, Indianapolis, Ind., Air Service.
Rantoul, Ill., Air Service.
Des Moines, Iowa, municipal.
Omaha, Nebr., Government, not Air Service.
Hastings, Nebr., municipal.
St. Paul, Nebr., municipal.
Cheyenne, Wyo., Government, not Air Service.
Rawlins, Wyo., municipal.
Salt Lake City, Utah, municipal.
Elko, Nev., municipal.
Sacramento, Calif., Air Service.
San Francisco, Calif., Air Service.

One route from Savannah, Ga., to San Diego, Calif.:

Savannah, Ga., municipal.
Camp Benning, Ga., Air Service.
Montgomery, Ala., Air Service.
Baton Rouge, La., municipal.
Lake Charles, La., municipal.
Houston, Tex., Air Service.
San Antonio, Tex., Air Service.
Del Rio, Tex., Air Service.
Sanderson, Tex., municipal.
El Paso, Tex., Government, not Air Service.
Douglas, Ariz., Government, not Air Service.
Tucson, Ariz., municipal.
Phoenix, Ariz., municipal.
Yuma, Ariz., Government, not Air Service.
San Diego, Calif., Air Service.

One route north to south on the Atlantic coast:

Augusta, Me., already mentioned.
Boston, Mass., municipal.
Mitchel Field, Long Island, Air Service.
Bustleton, Pa., Government, not Air Service.
Aberdeen, Md., Air Service.
Baltimore, Md., municipal.
Washington, D. C., Air Service.
Langley Field, Va., Air Service.
Camp Bragg, N. C., Air Service.
Camp Jackson, S. C., Air Service.
Savannah, Ga., already mentioned.
Jacksonville, Fla., Government, not Air Service.
Daytona, Fla., municipal.
Carlstrom Field, Fla., Air Service.
Miami, Fla., Air Service.

One route along the Pacific coast:

Camp Lewis, Wash., already mentioned.
Portland, Oreg., municipal.
Red Bluffs, Calif., Government, not Air Service.
Sacramento, Calif., already mentioned.
Fresno, Calif., private.
Riverside, Calif., Air Service.
San Diego, Calif., already mentioned.

One middle route from north to south:

Laredo, Tex., Air Service.
San Antonio, Tex., already mentioned.
Dallas, Tex., Air Service.
Waco, Tex., municipal.
Wichita Falls, Tex., municipal.
Post Field, Okla., Air Service.
Little Rock, Ark., municipal.
Tulsa, Okla., private.
Leavenworth, Kans., Government, not Air Service.
Omaha, Nebr., Government, not Air Service.
Aberdeen, S. Dak., municipal.
Fargo, N. Dak., already mentioned.

One route from the Lakes to the Gulf:

Chicago, Ill., already mentioned.
Chanute Field, Rantoul, Ill., Air Service.
Belleville, Ill., Air Service.
Millington, Tenn., Air Service.
Jackson, Miss., municipal.
Baton Rouge, La., already mentioned.

In the establishment of these airways it is found that the various municipalities are usually glad to contribute the actual landing fields if the Federal Government will furnish the necessary equipment to operate such a field. The installation provided will depend largely upon the number of reserve personnel in the immediate vicinity that would rely upon this installation for their flying training.

The type installation is as follows:

1 wing cone with proper support and field marker T	$150
1 well with pump, 100-gallon tank	1,000
1 building, 25 by 100 feet, to contain the field-office lockers, meteorological office and emergency hospital and for use as a machine shop, supply storage, and workroom	25,000
1 oil tank, approximately 500 gallons, with pump	750
1 oil house, 10 feet square	850
1 gas tank with approximately 1,000 gallons capacity, with pump	1,000
1 hanger, steel, size 66 by 120 feet, with steel folding or sliding doors and cement floors	35,000
Total	63,750

It will be noted that in this type installation only one hanger is furnished. In many cases it will be necessary to have at least three hangars. In centers like Philadelphia and Boston this means the addition of $70,000 to the above amount.

It is estimated that to establish completely this proposed net would cost approximately $2,000,000. In the estimate for the fiscal year 1922 there was requested $1,000,000 as a start on this proposed scheme. It was desired to begin with the most important centers, such as Boston, Philadelphia, Baltimore, Chicago, St. Paul, Minn., Denver, Colo., Kansas City, and Seattle, Wash.

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APPENDIX C.

NECESSARY AEROLOGICAL SERVICE AND ESTIMATE OF COSTS.

A rational development of any program of navigation of the air must recognize meteorology and weather forecasting as a fundamental factor of great importance. The Weather Bureau was originally created by joint resolution of Congress approved February 9, 1870, placing the organization under the Chief Signal Officer of the Army, in the War Department, where it remained and developed for a period of about 20 years.

ORGANIC ACT.

The joint resolution was superseded by legislation entitled "An act to increase the efficiency and reduce the expenses of the Signal Corps of the Army, and to transfer the Weather Service to the Department of Agriculture." (Act. Oct. 1, 1920, ch. 1266, 266 Stat., 653.)

This organic act became effective July 1, 1891, and defines and outlines the functions and duties of the Weather Bureau very comprehensively and fully in the following language:

"SEC. 3. That the Chief of the Weather Bureau, under the direction of the Secretary of Agriculture, on and after July 1, 1891, shall have charge of the forecasting of weather, the issue of storm warnings, the display of weather and flood signals for the benefit of agriculture, commerce, and navigation, the gauging and reporting of rivers, the maintenance and operation of sea coast telegraph lines and the collection and transmission of marine intelligence for the benefit of commerce and navigation, the reporting of temperature and rainfall conditions for the cotton interests, the display of frost and cold-wave signals, the distribution of meteorological information in the interests of agriculture and commerce, and the taking of such meteorological observations as may be necessary to establish and record the climatic conditions of the United States, or as are essential for the proper execution of the foregoing duties."

With the practical development of navigation of the air a new demand was at once made upon the Weather Bureau for service in aid of aviation, and it is construed that the words of the organic act "for the benefit of agriculture, commerce, and navigation" obviously includes navigation of the air as well as of the oceans and inland waterways. Congress itself has in effect subscribed to this construction of the law, because in 1917 an appropriation was made for the conduct of this work under the following language:

"For the establishment and maintenance by the Weather Bureau of additional aerological stations, for observing, measuring, and investigating atmospheric phenomena in the aid of aeronautics, including salaries, travel, and other expense in the city of Washington and elsewhere."

This appropriation was first included in the act making appropriation for the support of the Army for the fiscal year ending June 30, 1918, and has subsequently been continued in the annual appropriation bills for the Weather Bureau of the Department of Agriculture.

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AUTHORITY OF LAW NOW ADEQUATE.

It is believed the foregoing completely establishes that the Weather Bureau has full existing authority of law for the conduct of meteorological work of every character required for aeronautics, and under these laws the bureau has been conducting as large a program of work as is possible with the funds available.

METEOROLOGY AND WEATHER FORECASTING A UNIT.

In the organization of Government operations and activities with reference to meteorology and aviation, it is deemed to be a fundamental proposition that the whole problem of meteorological advices and warnings constitute a unit, for this service can only be administered when a comprehensive system of observations are available from a network of stations furnishing the fullest possible data concerning the conditions of the atmosphere, not only over the continents but over the oceans and at all altitudes accessible.

On this principle, prior to the war, the Weather Bureau received by international cooperation, reports from the entire Northern Hemisphere and published a daily weather map of the same. This ser · ce, suspended by the war, is now only partly restored. For 50 years the Weather Bureau has been an essential unit dealing with meteorology. Segregation of essential functions and activities, or the assignment of portions of its work to other organizations, can not be accomplished without loss of efficiency or great increase in cost and duplication and conflict of effort, because the fundamental system of complete observations and reports must be available for study and application by an agency attempting to furnish advices and forecasts.

POLICY AND PROGRAM.

Any program of meteorological work in aid of aeronautics is necessarily very intimately associated and interlocked with general meteorological work, forecasts, warnings, and advices of every character. For this service it is fundamentally essential to maintain a comprehensive network of stations over the entire continental area of the United States from which observations and reports are regularly and systematically received, including observations of the free air. Where practicable, by international cooperation and otherwise, such reports must be supplemented by reports from the other continents and the oceans.

In the specific interests of aviation this system of stations must include stations for the making of observations in the free air by the use of kites, balloons, and other agencies. At present only six completely equipped stations are in operation, supplemented by a small number of stations at which only pilot balloon observations are made. Reports furnish twice daily the direction and velocity of motion of the free air in different altitudes at from about 500 meters to about 3,000 or 4,000 meters above the surface of the earth. Results are telegraphed promptly to Washington twice a day and are used in furnishing daily forecasts and warnings, which are sent to the aviation branches of the Army, the Navy, the Post Office Department, aeronautical clubs, and all civilian interests who can utilize and desire the advices and information.

Present appropriations.—The amount of money expended for all purposes identified immediately with the exploration of the free air is at present $81,020, this being the total of the appropriation for the year 1920–21. For 1921–22 the same appropriation, $81,020, is available.

The above sum is supplemental to the general appropriations of the Weather Bureau for all purposes, and the general resources of the Weather Bureau are, of course, available to supplement the actual sum appropriated for aviation purposes.

RESULTS NOW BEING OBTAINED.

Prior to 1917 the Weather Bureau conducted a single observation station for the exploration of the upper air and published results of these observations more or less in detail in the bulletins of the Mount Weather Observatory. Subsequently it issued a five-year summary of these observations, giving details of upper air conditions. These results are very valuable and were greatly in demand by artillerists, aeronauts, and others during the period of the war and were quoted and referred to in connection with a great many problems dealing with free air conditions. Upon the establishment of five additional kite stations the observational data began to be published as promptly as possible in the supplements of the Monthly Weather Review, which also were in demand and used during the period of the war. From lack of funds the publication of the supplements had to be suspended, but the free air data are being analyzed and studied, and a three-year summary from the six aerological stations is in process of compilation. A considerable number of special studies of free air phenomena, as shown by observations, have been made and the results published in the Monthly Weather Review. Systematic forecasts of conditions for aeronauts were anonunced to begin December 1, 1918. These have been continued ever since and very considerably extended. The whole service of the Weather Bureau in aid of aviation is in a plastic form, subject to change and development as experience and needs indicate. Specific service was rendered in connection with the trans-Atlantic flights, both of the *NC-4* and the British airship, and on every occasion of any aeronautical event the Weather Bureau has been alert to make its advices and information directly available and beneficial in every way possible.

PROPOSALS FOR DEVELOPMENT.

Progress in the meteorological science and its applications requires an accumulation of observational data of atmospheric phenomena and conditions over a consideralbe period of time.

Additional stations needed.—Eight primary stations should be established at the earliest possible date, to bring the total up to 14. Including cost of equipment, salaries, telegraphing, and summarizing the results, these stations would require an annual expenditure of about $22,500 each. The total cost for the 8 stations annually, would be $180,000. At least one additional station should be established each ensuing year until a total of 20 primary stations for the entire United States has been secured.

ACTUAL METEOROLOGICAL SERVICE ALONG AIR ROUTES.

Whenever an air route for regular traffic is established, the meteorological service necessary for that particular route should be set up even in advance of the time the air route is in actual practical operation. For each 1,000 miles of independent airway established and put in more or less complete operation the Weather Bureau should maintain a concentrated service of such route. This will require supplemental stations at intervals of about 250 miles, and the plan comprehends even additional reports from cooperative observers at intermediate points, giving visibility, local cloudiness, squalls, etc., so that at any time an aviator along the route would know the actual conditions at places toward which he may be flying. The cost of establishing and fully maintaining and operating these stations at intervals of 250 miles is estimated at $5,000 each, or a total of $25,000 for each independent 1,000 miles of air route. At the present time there are approximately 4,000 miles of air routes authorized and in more or less regular operation. Meteorological reports and information are now needed for these aeronautical operations. In addition, flying is practiced more or less regularly over additional courses also needing the benefits of meteorological advices and warnings.

SUMMARY.

The appropriations estimated to be necessary to meet the present and prospective requirements of aeronautics within the next five years are as follows:

For 8 primary stations essential to fundamental studies of conditions in the free atmosphere	$180,000
Secondary stations for 4,000 miles of authorized air routes and for special and supplementary flying	220,000
Total	400,000

Annual extensions.

1 additional primary station per year for 6 years or until 6 are added	$22,500
Supplementary stations along established air routes for each 1,000 miles of continuous airway	20,000
Total	42,500

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APPENDIX D.

COOPERATION AMONG THE VARIOUS DEPARTMENTS OF THE GOVERNMENT CONCERNED WITH AVIATION.

WAR AND NAVY DEPARTMENTS.

The cooperation between the Air Services of the Army and Navy Departments is provided by a joint Army and Navy aeronautical board, whose duty is to prevent duplication and to secure coordination in the construction of aircraft experimental stations and all operating air stations used by the Army, Navy, or both. All questions relating to the development of new types of aircraft and weapons to be used by aircraft are referred to the aeronautical board to determine which department should properly be charged with its development. All matters of procurement and purchase of aircraft and the estimates for the appropriations for the Army and Navy aviation programs are presented to this board for review and recommendation before submission to Congress. Training facilities are interchanged and existing law provides for the interchange of material.

WAR, NAVY, AND POST OFFICE DEPARTMENTS.

The War, Navy, and Post Office Departments cooperate extensively in the following ways: Surplus aeronautical equipment in possession of the Army or Navy for which the Post Office Department has a definite use is transferred freely, the Post Office Department having the opportunity to obtain this material before it is offered for sale. Air mail stations, especially those on the New York-San Francisco airway, are used by the Army and Navy, and in turn the air mail service has the use of the Army fields, repair depots, and the facilities of the naval aircraft factory. Army, Navy, and air mail pilots in distress may obtain assistance and supplies from the air stations of each department without discrimination. There is complete interchange of technical and engineering data, operating reports, and general information. In addition, the air mail pilots and mechanics must have passed the Army or Navy aviation physical examination, and in case of questions as to the physical fitness of any air mail pilot or mechanic he is reexamined by the Military or Naval Air Service medical departments. Other governmental agencies, such as the Bureau of Standards, Bureau of Mines, and Weather Bureau, render the technical assistance for which they are especially fitted.

EXPERIMENTAL AND RESEARCH DEVELOPMENT.

Coordination of experimental and research work is provided for by the subcommittees of the National Advisory Committee for Aeronautics. The organization of the National Advisory Committee for Aeronautics provides for subcommittees of power plants for aircraft, materials for aircraft, and aerodynamics. Each department of the Government, as well as the different branches of the aircraft industry, are represented in the membership of the various subcommittees. The proposed and active research and experimental development of each governmental department is reported to the subcommittees, thus preventing unnecessary duplication. The subcommittees further provide means of exchange of information and ideas which permits the industry and the various departments to familiarize themselves with the research that is in progress.

NAVY AND DEPARTMENT OF COMMERCE.

(a) *Geodetic Survey.*—The Air Service of the Navy is now engaged in mapping the Mississippi Delta for the Coast and Geodetic Survey, and has completed the mapping of swamps in South Carolina for the same service.

(b) *The Bureau of Fisheries.*—The Navy has demonstrated to the Bureau of Fisheries the practicability of locating schools of fish and reporting their location to fishermen. This service has been extended to the point where it was shown that it would be practicable to maintain an airplane service for this purpose.

NAVY AND TREASURY DEPARTMENT.

(a) *Coast Guard.*—The Navy Air Service has cooperated with the Coast Guard in the training of pilots and the transfer of equipment to this organization.

NAVY AND DEPARTMENT OF AGRICULTURE.

(a) *Weather Bureau.*—The Weather Bureau has cooperated to the extent of its facilities in providing meteorological information to the Navy. A meteorological interdepartmental committee has been organized to coordinate the needs and services of all the governmental departments operating airplanes.

WAR DEPARTMENT AND DEPARTMENT OF AGRICULTURE.

(a) *Forest Service.*—An aerial survey is being made of the recent Olympic blow down of the State of Washington, where over 8,000,000,000 board feet of timber has been destroyed. Forest fire patrol will be continued and will require approximately 1,000,000 miles of flying per year.

(b) *Bureau of Farm Management.*—Photographs have been made of agricultural districts in order to obtain photographs by means of which farm management and development may be improved.

(c) *Bureau of Entomology.*—Various areas have been photographed for the Bureau of Entomology and experiments are being made for the purpose of locating rust spores in the upper air currents.

(d) *Weather Bureau.*—The Air Service has cooperated with the Weather Bureau in various capacities, especially in connection with obtaining meteorological information.

WAR DEPARTMENT AND TREASURY DEPARTMENT.

Aerial photographs of various areas are being made for the use of the United States Public Health Service.

WAR DEPARTMENT AND DEPARTMENT OF THE INTERIOR.

Geological Survey.—Geological surveys are being made of various areas such as Bibb County, Ga., Greater New York, New York Harbor, 2,708 square miles in North Carolina, some 4,000 square miles in the vicinity of Los Angeles, and many other areas totaling some 20,000 square miles. For the same department the Air Service is cooperating with the director of national parks and the chief of the Reclamation Service.

WAR DEPARTMENT AND DEPARTMENT OF COMMERCE.

Coast and Geodetic Survey.—Areas near the head of the Chesapeake Bay, Atlantic City, and Florida Reefs are being photographed from the air; also the coast of New Jersey, from Cape May to Sandy Hook. By means of aerial photographs a revision of the charts of the James River from Hampton Roads to Richmond and the coast lines of South Carolina, Georgia, and Florida are being accomplished. Aerial photographs of various forest areas, public buildings, rivers, and cities are being taken whenever facilities become available. Among the important examples of this type of work may be quoted: Forest areas of the Adirondack region and the State of Pennsylvania, public buildings and grounds of the District of Columbia, 1,200 miles of the Red River Basin between the States of Oklahoma and Texas, and the Tennessee River Basin. Photographs for the secretary of the Commission of Fine Arts are being made to aid him in planning the new botanic gardens.

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APPENDIX E.

COOPERATION OF WAR AND AGRICULTURAL DEPARTMENTS AND OPERATING COST OF FOREST FIRE PATROL.

[By Air Service of the Army.]

1. These figures do not include the overhead, such as cost of initial equipment or airplanes nor personal expenses and salaries of operating personnel, which are covered in the specific Army appropriations for that purpose.

(a) Year 1921, program covering California and Oregon alone.

Estimate of actual money expended.

(a) Maintenance of airplanes and their spare parts, 37 planes, at $200 per plane	$7,400.00
(b) Maintenance of engines and their spare parts, 50 engines, at $200 each	10,000.00
(c) Fuel and oil, based on 28 gallons per hour, at 35 cents per gallon, and 1½ gallons of oil, at $1 per gallon:	
Gasoline	35,660.80
Oil	5,994.00
Total	59,054.80

(b) Estimate for fiscal year 1922, extended forest fire patrol. This program will not be carried out due to lack of (a) appropriations, (b) personnel, (c) instructions from General Staff adopting first alternative (that is, a reduction) of the three alternatives set forth.

This would allow the forest fire patrol to include Washington, Idaho, Montana, and a small portion of Wyoming, a total of five squadrons, 160 officers and 660 enlisted men.

Estimated cost.

(a) Maintenance of airplanes and their spare parts	$54,026
(b) Maintenance of engines and their spare parts	47,253
(c) Cost of fuel and lubricants	115,872
Total	217,151

N. B.—This does not include the appropriation of $50,000 obtained by the Department of Agriculture for cooperation with the Air Service and forest fire protection and expended under the supervision of the Department of Agriculture and its officers.

AIRSHIP DEVELOPMENT.

Germany and England have produced the best demonstrations of the potential value of rigid airships, both for military and commercial purposes. Germany, in particular, has demonstrated the practicability of commercial airship passenger service. The French Government has laid out a progressive program of development. France has two rigid airships of the Zeppelin type, which were acquired from Germany through the Reparations Commission. The present French program calls for the early inauguration of a commercial airship line from Marseille or Toulon to Algiers. In Italy, the semirigid type of airship has been developed, both for military and commercial purposes.

America's first program of airship development contemplated the procuring by the Navy of a rigid airship from England—the ill-fated *R-38*, known in this country as the *ZR-2;* the procuring by the Army of the Italian semirigid airship *Roma;* and the construction by the Navy at Lakewood, N. J., of the first American rigid airship, to be known as the *ZR-1*.

The disaster to the *ZR-2* in Great Britain before delivery to this country threatened for a time the discontinuance of airship development in America. The National Advisory Committee for Aeronautics, in a special resolution addressed to the President and to the Secretaries of War and of the Navy in September, 1921, pointed out the tremendous advantage possessed by America by reason of its virtual monopoly of the known sources of supply of helium, and urged the continuance of our airship development program, stating that it would be contrary to the true American spirit to abandon a conservative program of development because of a single disaster. The committee renews its recommendations then made, that the development of airships be continued, and that sufficient funds be provided for experimental work for the, obtaining of definite information regarding the strength qualities of materials and girders used in the construction of airships, and for the development and checking of the theories used in the general design of airships.

As the techinque of airship construction has not as yet been developed in this country, the committee believes it advisable, in the interests of rapid and economical progress, that the Goverment procure a rigid type of airship, either of German or British manufacture, embodying the latest developments, as far as possible, of both countries. Such an airship is an indispensable part of our program, and should be obtained to fill the vacancy caused by the loss of the *ZR-2*. The committee also renews its recommendation that the present program for the construction of the *ZR-1* at Lakewood, N. J., be prosecuted with renewed vigor.

HELIUM FOR AIRSHIPS.

Helium, next to hydrogen, is the lightest gas known. It has 92 per cent of the lifting power of hydrogen, and for military purposes possesses an inestimable advantage over hydrogen in that it is nonflammable. The natural-gas wells in the United States afford a practical monopoly of the known sources of supply. According to the latest estimates, helium is escaping into the atmosphere at the rate of one and a quarter million cubic feet a day, or at a rate sufficient to fill four large airships a week. At this rate, according to our present knowledge of helium-bearing gas, our great resources will have become dissipated within the next 20 years unless some appropriate measures are taken to preserve the sources of supply.

The refrigeration process is employed to obtain helium. In this process every constituent present in the natural gas is liquified except helium, which is expelled into suitable containers for storage. The application of this process to the extraction of helium has not been perfected, but the line of development is reasonably clear. The Army, the Navy, and the Bureau of Mines, acting in close cooperation (with the limited funds available), are carrying out certain developments which promise to solve the production problem.

The Bureau of Mines is also conducting experiments to determine whether underground-chamber storage is practicable and economical. If so, the problem may be resolved into one of conservation by the storage of helium in its natural state. Helium for current uses, however, will continue to be stored in high-pressure containers until used.

In connection with the consideration of an airship development policy, the committee presents as the crystalized opinion of the Government experts who have studied the helium problem that in helium the United States has exclusive possession of a valuable adjunct to national defense which will be wasted unless conservation is provided for without delay.

The National Advisory Committee for Aeronautics therefore recommends that the Government acquire and seal for future use the best helium-producing gas fields; that such experiments be continued as are involved in the development of an efficient and economical process for the extraction and repurification of helium; and that the Government continue experimental work in connection with the development of airships, and inaugurate without delay the use of airships inflated with helium. With large reserves of helium and the development of types of airships to fully realize the advantages to be derived from the use of helium, America would possess resources and knowledge with which no other nation could successfully compete.

THE ELECTROSTATIC PROBLEM FOR AIRSHIPS.

The question of the danger to airships from static charges of electricity and from lightning was referred to the committee, and a large amount of data was collected. In the end the procedure adopted by the Navy Department was investigated and approved.

THE AIR MAIL SERVICE.

In January, 1921, the committee submitted the following special report to the Congress through the President, setting forth its views as to the value to the Nation of the Air Mail Service of the Post Office Department:

To the Congress:

The executive committee of the National Advisory Committee for Aeronautics, at a meeting held on January 13, 1921, had under consideration the present status of the Air Mail Service of the Post Office Department and the probable effect on the development of aeronautics in America of the discontinuance of this activity, which has been threatened by the elimination on the floor of the House of the appropriation for its continuance.

It is the opinion of the National Advisory Committee for Aeronautics that the Air Mail Service is in effect an experimental laboratory for the development of the civil uses of aircraft, and, viewed from this angle alone, is worth what it costs over and above the value of the service it actually renders in the more rapid transportation of mail.

The Sixth Annual Report of the National Advisory Committee for Aeronautics contained a statement of a national aviation policy, in which the need of Federal encouragement for the development of commercial aeronautics war emphasized and the definite recommendation made that the Air Mail Service of the Post Office Department be furthes extended and developed.

The increasing relative importance of aircraft in warfare not only justifies but makes imperative the expenditure of public funds to aid the development of commercial aeronautics, on which military and naval aeronautics will be largely dependent. The Air Mail Service has given the best demonstration of the practicability of the use of aircraft for civil purposes, and, in the face of many obstacles, has accomplished remarkable results of real and permanent value to the Nation at relatively slight cost. It is the unanimous opinion of the National Advisory Committee for Aeronautics that the Air Mail Service of the Post Office Department should be continued.

The reasons for this special report are set forth in the following resolution, which was adopted without a dissenting vote on January 13, 1921:

"Whereas the Air Mail Service of the Post Office Department has given to the world the best demonstration of the practicability of the uses of aircraft for civil and commercial purposes, and has greatly promoted the commercial development of aircraft; and

"Whereas the development of the civil and commercial uses of aircraft is essential to the maintenance of an aircraft industry in such a condition as to permit the necessary expansion in time of war, unless the taxpayers of the country are willing to pay, through Army and Navy expenditures, practically the entire cost of maintaining the industry; and

"Whereas the civil development of aviation will aid military development and will in time bring about the establishment of air routes and landing fields more or less generally throughout the United States, which will be an important military asset in time of war; and

"Whereas the Air Mail Service has already contributed to the progress of civilization by improving the means of business communication and transportation; and

"Whereas the Army and Navy Air Services are by law limited to the development of types of aircraft for military and naval purposes which do not satisfactorily meet commercial needs; and

"Whereas the needs of other civil agencies of the Government, such as the Forest Service, the Coast Guard Service, the Coast and Geodetic Survey, require the development of nonmilitary types of aircraft; and

"Whereas the operation of the Air Mail Service is at the present time an essential part of the organized plan for the development of commercial aviation as contained in the national aviation policy formulated by this committee, and the cost of fostering such an organized plan is much less than the waste that would inevitably result from unprepared entry into war; and

"Whereas several European countries are supporting the development of commercial aviation, the discontinuance of the Air Mail Service will be a backward step in the development of aviation and will retard for a number of years the establishment of landing fields generally: Therefore, be it

"*Resolved*, That it is the opinion of the National Advisory Committee for Aeronautics that the Air Mail Service is in effect an experimental laboratory for the development of the civil uses of aircraft, and that, viewed from this angle alone, it is worth what it costs over and above the value of the service it actually renders in the more rapid transportation of mail;

"*Resolved further*, That the National Advisory Committee for Aeronautics submit a special report to the Congress through the President, stating that in its opinion the increasing relative importance of aircraft in warfare and the need for adopting and carrying through a sane, sound policy for the development of civil aviation, such as is outlined in the statement of a national aviation policy contained in the Sixth Annual Report of the National Advisory Committee for Aeronautics, not only justifies but makes imperative the expenditure of public funds to aid the development of commercial aeronautics; and that, as an existing agency which has, in the face of many obstacles, accomplished remarkable results of real and permanent value to the Nation, and at relatively slight cost, the Air Mail Service of the Post Office Department should be continued."

Respectfully submitted.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
JOSEPH S. AMES, *Chairman Executive Committee.*

The message of President Wilson, in transmitting the above report to the Congress under date of January 24, 1921, was as follows:

To the Senate and House of Representatives;

I transmit herewith for the consideration of the Congress a special report of the National Advisory Committee for Aeronautics, in which the committee sets forth its views as to the value to the Nation of the Air Mail Service of the Post Office Department, based on broad, general considerations of national interest and policy.

I concur in the opinions expressed by the National Advisory Committee for Aeronautics, and indorse its recommendation for the continuance of the Air Mail Service.

Subsequently, in April, 1921, the committee submitted to President Harding a special report dealing with Federal regulation of air navigation, air routes to cover the whole United States, and cooperation among the various departments of the Government concerned with aviation, which was published as House Document No. 17. In that report the committee recommended that the Post Office Department be authorized to extend the Air Mail Service by the establishment of air mail routes between Chicago, Minneapolis, and St. Paul, and between Chicago and St. Louis. This recommendation was based upon the advisability of affording greater encouragement for the development of civil aviation. Regardless of whether the Air Mail Service is to continue to be operated directly by the Government indefinitely, or as a private enterprise under contract with the Post Office Department, the service should be extended and developed. Eventually the service should be operated by private enterprise, that is, in so far as the air transportation is concerned; but before this will be economically practicable other necessary aids to commercial aviation, as recommended elsewhere in this report, should be afforded by the Federal Government.

THE AIR MAIL RADIO SERVICE.

The radio section of the Air Mail Service, organized to facilitate communications between fields and between fields and airplanes in flight, now has 16 land radio stations in operation. Communication between fields is almost instantaneous over a 16-hour period each day. Development has covered the practical application of airplane radio communication and radio direction finding. Airplane radio is being utilized as fast as appropriations permit.

In addition to air mail communications, this chain of radio stations provides an emergency communication system for the Post Office Department and other branches of the Government connecting all the important cities between Washington, New York, and San Francisco. It also forms the nucleus of a broadcasting system which now covers half the area of the United States.

CANADA'S CONTINUED COURTESY TO AMERICAN AIR PILOTS.

In June, 1920, the committee received from the State Department information to the effect that the Canadian Air Board had promulgated regulations permitting United States qualified aircraft and pilots to fly in Canada until November 1, 1920, on the same basis as if the United States had established air regulations as contemplated under the Convention for the Regulation of International Air Navigation. The Canadian Air Board has repeatedly extended this for successive periods of six months, and it remains a matter of courtesy pending the enactment of a separate treaty with Canada on the subject, because our Government has not ratified the Convention for the Regulation of International Air Navigation. In May, 1921, the Secretary of State requested the advice of the committee on the subject of further extensions of these courtesies by the Canadian Air Board. The committee, by resolution adopted at its meeting held on May 12, 1921, recommended that the State Department accept, on behalf of the Government of the United States, a further extension by six months of the period during which American pilots and aircraft will be permitted to fly in Canada under existing conditions; and that the State Department express to the Government of Canada the deep appreciation of the Government of the United States for the repeated courtesies of the Government of Canada in this matter, and at the same time express the hope that Federal legislation may be enacted at an early date which may lead to a more permanent and definite solution of the matter.

The committee at that time also reported to the Secretary of State that in its opinion the existing situation was highly undesirable, and served to emphasize the need for the early enactment of Federal legislation for the regulation of air navigation, and the committee recommended that the Secretary of State bring the matter to the attention of the President and the Congress with a view to securing the enactment of the necessary legislation.

INTERNATIONAL CONVENTION ON AIR NAVIGATION.

During the past year the committee has given consideration to a number of questions referred to it by the State Department, arising under the provisions of the International Convention of Air Navigation. The committee had, in September, 1919, and in May, 1920, recommended the ratification of this convention with certain reservations. In July, 1921, the committee, in response to an inquiry of the State Department, reaffirmed its opinion that the convention should be ratified in accordance with its previous representations and subject to the reservations recommended. If the International Convention on Air Navigation is not ratified by the United States, it is then the opinion of the National Advisory Committee for Aeronautics that a separate treaty regulating air navigation between the United States and Canada should be executed.

SAFETY CODE FOR AVIATION.

The extreme importance of establishing a safety code in aviation has been recognized by both the Army and the Navy and by manufacturers and others directly concerned with aviation. There is a general feeling, however, that great care should be exercised in the establishment of a safety code for aviation, to prevent, if possible, restrictions which will unnecessarily hamper the development of aviation.

As all national safety codes are established under the direction of the American Engineering Standards Committee, it was felt advisable in this case to have the safety code initiated by this body. The American Engineering Standards Committee, at its meeting on October 9, 1920, appointed a sectional committee for safety codes, with the Bureau of Standards and the Society of Automotive Engineers acting as joint sponsors for that committee. The following organizations were requested to designate representatives on the sectional committee for the safety code for aviation: War Department, Navy Department, Post Office Department, Coast Guard, National Advisory Committee for Aeronautics, National Safety Council, Underwriters' Laboratories, National Aircraft Underwriters' Association, United States Forest Service, Manufacturers Aircraft Association, Aero Club of America, American Society of Mechanical Engineers, and American Society of Safety Engineers.

The Bureau of Standards and the Society of Automotive Engineers, acting as sponsors, prepared a complete synopsis of a safety code for aviation, which was distributed to the various organizations to be represented on the sectional committee. A meeting for organization purposes was held in Washington on May 13, 1921, for the consideration of the scope and method of development of the proposed safety code for aviation. A meeting for organization was held in New York, September 7, 1921, at which a permanent organization was effected, the officers consisting of a chairman, Mr. H. M. Crane, Society of Automotive Engineers; vice chairman, Dr. Joseph S. Ames, National Advisory Committee for Aeronautics; and secretary, Mr. M. G. Lloyd, Bureau of Standards. Five subcommittees were appointed to deal with the subject matter of safety codes covering, respectively, the following subjects: Airplane structure, including design, construction, and test; power plants for aircraft, including design, construction, and test; equipment and maintenance of airplanes; lighter-than-air craft, including balloons, airships, and parachutes; airdromes and traffic rules, including landing fields, air ports, traffic rules, signals, and qualifications for pilots.

THE AERONAUTICAL BOARD OF THE ARMY AND NAVY.

The Aeronautical Board was appointed by the Secretary of War and the Secretary of the Navy, and is composed exclusively of Army and Navy officers. It has no official connection with the National Advisory Committee for Aeronautics, its functions being the consideration of military questions regarding the use of aeronautics in both services. The committee feels that there is a positive need for such a joint board; in fact, the present Aeronautical Board is a development of the Joint Army and Navy Technical Aircraft Board which was established during the war on the recommendation of this committee. There is no friction or duplication of functions whatsoever between the Aeronautical Board and this committee. On the contrary, a cordial contact has always existed in the work of the two organizations.

ASSISTANCE FROM ARMY AND NAVY.

The Army and the Navy Air Services have greatly contributed to the success of the research work in general conducted by the committee at the Langley Memorial Aeronatical Laboratory by placing at the service of the committee the necessary airplanes and accessories. The committee appreciates the cooperation given by the Army and Navy Air Services in the carrying out of research programs, and desires especially to acknowledge the many courtesies extended by the Army authorities at Langley Field, where the committee's laboratories are located.

WORK IN PROGRESS FOR THE ARMY AND THE NAVY.

As a rule, the technical subcommittees, including representatives of the Army and Navy Air Services, prepare programs of research work of general use or application, and these programs, when approved by the National Advisory Committee for Aeronautics, furnish the problems for solution by the Langley Memorial Aeronautical Laboratory. The cost of this work is borne by the committee out of its own appropriation. If, however, the Army Air Service or the Naval Air Service desires specific investigations to be undertaken by the committee, for which the committee has not the necessary funds, the regulations as approved by the President provide that the committee may undertake the work at the expense of either the Army or the Navy.

The work thus undertaken by the committee during the past year may be outlined as follows:

For the Engineering Division of the Air Service of the Army.—The committee's technical assistant in Europe purchased samples of foreign aeronautical instruments.

An investigation of the measurement of airplane oscillations with a kymograph was made at the Langley Memorial Aeronautical Laboratory.

A special type of accelerometer has been designed and constructed at the committee's laboratory.

A photographically recording air-speed meter, a special gyroscope for recording rate of turn, and a photographically recording multiple manometer for the measurement of the distribution of pressure on the different elements of an airplane have been designed and constructed at the committee's laboratory.

A study of fog landing devices has been undertaken with a view to reporting on the acoustical, electrical, and pressure methods.

For the Naval Air Service.—The design and development of an internal-combustion engine of the fuel-injection type has been undertaken at the committee's laboratory.

A research on the relative wing loading of biplane and triplane combinations, with variation in stagger, has been undertaken at the committee's laboratory.

An investigation of the aerodynamic properties of model aircraft to be tested in the new compressed-air wind tunnel has been inaugurated.

The committee's office of aeronautical intelligence has translated and prepared reports in English of aeronautical research and experimentation conducted in Germany during the war.

CONSIDERATION OF AERONAUTICAL INVENTIONS.

On the initiative of the inventions section of the Navy Department, an agreement has been reached between the department and the committee whereby all inventions of a general character relating to aeronautics which are received in the Navy Department are referred to the committee for consideration and proper action. The committee examines the invention, conducts the necessary further correspondence with the inventor, and if the invention is of prospective value makes a report to the Navy Department, a copy of which is sent to the Army Air Service. The agreement with the Navy Department was definitely approved by the Secretary of the Navy on April 12, 1921. In like manner, although without formal agreement, the committee considers inventions referred to it by the Army Air Service, and if any such inventions appear to be promising a copy of the report is sent to the Naval Air Service.

REPORTS FROM COMMERCIAL ATTACHÉS.

The Department of Commerce has, on request of the committee, instructed its commercial attachés and trade commissioners in England, France, Italy, Germany, and Holland to obtain reports and current information on developments in commercial aviation and forward same to this country for the use of the committee. Consular officers of the State Department, in all countries where any aeronautical activities exist, have been similarly instructed by the State Department. All the information that is received by the National Advisory Committee for Aeronautics is recorded in the committee's Office of Aeronautical Intelligence, and in this way becomes promptly available to the members of the committee and the governmental agencies concerned. If the information is not confidential, it is also made available to aircraft manufacturers.

THE UTILIZATION OF NONGOVERNMENTAL AGENCIES.

Whenever practicable, research authorizations when approved are distributed by the committee among governmental agencies. When, however, a certain investigation requires the use of facilities not possessed in any governmental establishment, or requires the services of a man not connected with the Government service, the committee contracts direct with the individual or institution concerned for a "special report" on the subject. In this way the committee has marshaled the services of educational institutions and eminent specialists in this and other countries.

GENERAL EDUCATION IN AERONAUTICAL ENGINEERING.

The committee is engaged in the preparation of problems in aeronautics and answers thereto, which will be distributed among professors in engineering courses at various universities with a view to having the engineering students generally acquire some knowledge of aeronautical engineering. The committee believes that the future development of aeronautics will be aided by even a slight familiarity with the problems involved on the part of engineering graduates generally.

OFFICIAL NOMENCLATURE FOR AERONAUTICS.

The committee's report No. 91, entitled "Nomenclature for Aeronautics," issued in August, 1920, was officially promulgated by the Secretary of the Navy and the Chief of Air Service of the Army for their respective services. This report supersedes all previous reports on this subject. It was prepared by the committee with a view to securing uniformity with reference to aeronautical terms in official documents of the Government and as far as possible in commercial publications. The report is prepared in classified and dictionary forms, and includes a list of aeronautical symbols.

BIBLIOGRAPHY OF AERONAUTICS.

The Bibliography of Aeronautics for the years 1910–1916 has been issued by the committee during the past year. The publication of this work by the committee was specifically authorized by law by act of Congress approved July 1, 1918. It covers the literature published from July 1, 1909, to December 31, 1916, and is a continuation of the work of the Smithsonian Institution issued as volume 55 of the Smithsonian Miscellaneous Collections, which covered the material published prior to June 30, 1909. Citations of the publications of all nations are included in the languages in which the publications originally appeared. The arrangement is dictionary form, with author and subject entry, and one alphabetical arrangement. Detail in the matter of subject reference has been omitted on account of cost of presentation, but an attempt has been made to give sufficient cross reference to make possible the finding of items in special lines of research. This volume comprises nearly 1,500 pages.

The committee has also prepared a Bibliography of Aeronautics for the years 1917, 1918, and 1919, which will be issued in one volume during the coming year. Beginning with the year 1920, the bibliography for each year will be prepared and issued annually by the committee.

INDEX OF AVIATION CHEMISTRY.

The committee has made arrangements with Dr. Edward C. Worden for the preparation for publication by the committee of an index of the voluminous report on aviation chemistry prepared for the Bureau of Aircraft Production by Dr. Worden and others immediately following the armistice. The report itself is too large to warrant publication. Ten typewritten copies are in existence, and it is proposed to make these available for general reference by placing them in libraries in different parts of the country. It is thought by the committee that the publication of an index of this report on aviation chemistry will suffice to make the whole available to those interested.

THE GENERAL REPORT ON AERONAUTIC INSTRUMENTS.

On recommendation of the subcommittee on aerodynamics, the National Advisory Committee for Aeronautics authorized the undertaking, at the Bureau of Standards, of the preparation of a general report on aeronautic instruments.

As authorized by the Committee on Aerodynamics, this report includes a complete account of the status of aeronautic instruments at the end of the war, and covers the subject in detail up to the beginning of the year 1920. Since the date of authorization nearly a year and a half has been required by the Bureau of Standards for the actual preparation of the manuscript, which has involved the cooperative effort of 17 different individuals, many of whom have since left the Government service.

The general report consists of eight separate technical reports, Nos. 125 to 132, including a report on the general characteristics of aeronautic instruments and problems and a bibliography of aeronautic instruments, and complete separate reports covering the following instruments, which are classified according to their use: Altitude instruments; aircraft speed instruments; direction instruments; power-plant instruments; oxygen instruments; and aerial navigation and navigating instruments.

The technical reports covering the above instruments present a systematic, illustrated description of American, British, French, Italian, Swiss, Dutch, Danish, Austrian, and German aircraft instruments, together with the methods of testing developed at the Bureau of Standards, and a brief statement of the results of the investigations. In the compilation of the material of the general report on aeronautic instruments separate papers have been written by experts on the respective types of instruments.

The general report is completed by a report by Dr. F. L. Hunt, Chief of the Aeronautic Instruments Section of the Bureau of Standards, on the recent developments and outstanding problems in aeronautic instruments. This report serves to bridge the gap between the information as to the various classifications of instruments, which was carried up to 1920, and the present, and contains information as to the most recent developments in aeronautic instrument design and construction.

QUARTERS FOR COMMITTEE.

The administrative offices of the National Advisory Committee for aeronautics are located in the Navy Building, Seventeenth and B Streets NW., Washington, D. C. The technical work of the committee, conducted by or under the supervision of the various subcommittees, has been carried on in various governmental laboratories and shops, including the Bureau of Standards and the committee's own field station at Langley Field, Va., known as the Langley Memorial Aeronautical Laboratory, and also in various laboratories connected with institutions of learning whose cooperation in the conduct of scientific research in aeronautics has been secured.

THE LANGLEY MEMORIAL AERONAUTICAL LABORATORY.

In previous annual reports the committee described the progress made in the development of its field station at Langley Field, Va., for the prosecution of scientific research in aeronautics. The station now comprises three principal units, namely, an aerodynamical laboratory or wind tunnel, an engine dynamometer laboratory, and a research laboratory building, the latter including administrative and drafting offices, machine and woodworking shops, and photographic and instrument laboratories. The research laboratory and the wind tunnel building are of permanent brick construction; the engine dynamometer laboratory is housed in a temporary four-section steel airplane hangar.

The committee has recently completed the construction of a factory type building of brick and steel, designed to house the new compressed-air wind tunnel. It is expected that the new wind tunnel will be in operation about July, 1922.

The Langley Memorial Aeronautical Laboratory occupies a plot of ground known as plot 16, Langley Field, Va., the plot having been set aside for the committee's use by the Chief Signal Officer of the Army in 1916, at the time the site was selected as a proposed joint experimental station and proving ground for the Army and Navy air services and the advisory committee. The use of that plot of ground was officially approved by the Acting Secretary of War on April 24, 1919. The four buildings at present constituting the Langley Memorial Aeronautical Laboratory have been erected by the committee pursuant to authority granted by Congress.

COMPRESSED AIR WIND TUNNEL.

On June 9, 1921, the executive committee of the National Advisory Committee for Aeronautics authorized the construction at the Langley Memorial Aeronautical Laboratory of a compressed air type of wind tunnel designed by Dr. Max Munk, technical assistant of the committee.

The utility of the present type of wind tunnel is limited by the fact that owing to a "scale effect" the results of tests on the small models, which are usually about 1/20 scale, are not immediately applicable to the full-size machine. Obviously it is very desirable to obtain, if possible, test results which are strictly proportional to those obtained in free flight. This condition may be realized by the use of a wind tunnel in which the air is compressed to about 20 atmospheres or more in order to compensate for the difference in the "scale" or Reynolds number for the model and for the full-size airplane.

The wind tunnel under construction has a diameter of 5 feet, the wind tunnel proper being placed within a steel cylinder 15 feet in diameter and 34 feet long. The steel cylinder has been tested for an internal pressure of 450 pounds per square inch and is designed for an average working pressure of 300 pounds per square inch.

The design of the cylinder further provides for a large door at one end and means for observing and operating the balance and setting wing angles from without the cylinder. The design of the balance has been carefully considered and due provision is made for the large forces to be measured.

The wind tunnel motor is 300 horsepower and the Reynolds number will be controlled by changing the air density rather than by changing the air speed. The air compressing units consist of two 300-horsepower compound compressors which compress the air to 115 pounds per square inch. The air is compressed into a receiving chamber and is then compressed by a 175-horsepower duplex booster compressor to the desired pressure in the test chamber. With the compressor units selected it will require approximately one hour to fill the chamber with air at a pressure at 300 pounds per square inch and every provision is being made in the design to make it unnecessary to open the chamber until the model is completely tested. Provision is also being made to maintain constant density so as to take care of temperature variations.

This tunnel when in operation will test models with a span of about 2 feet, but the results will be strictly comparable to similar data for a full scale machine, with a span of 30 feet, flying at 100 miles per hour. The construction of the models will therefore require special study and care.

OFFICE OF AERONAUTICAL INTELLIGENCE.

The Office of Aeronautical Intelligence was established in the early part of 1918 as an integral branch of the committee's activities. Its functions are the collection, classification, and diffusion of technical knowledge on the subject of aeronautics to the military and naval air services and civil agencies interested, including especially the results of research and experimental work conducted in all parts of the world. It is the officially designated Government depository for scientific and technical reports and data on aeronautics.

Promptly upon receipt, all reports are analyzed and classified, and brought to the special attention of the subcommittees having cognizance, and to the attention of other interested parties, through the medium of public and confidential bulletins. Reports are duplicated where practicable, and distributed upon request. Confidential bulletins and reports are not circulated outside of governmental channels.

To efficiently handle the work of securing and exchanging reports in foreign countries, the committee maintains a technical assistant in Europe, with headquarters in Paris. It is his duty to personally visit the Government and private laboratories, centers of aeronautical information, and private individuals in England, France, Italy, Germany, and Austria, and endeavor to secure for America not only printed matter which would in the ordinary course of events become available in this country, but more especially to secure advance information as to work in progress, and any technical data not prepared in printed form, and which would otherwise not reach this country.

The records of the office show that during the past year copies of technical reports were distributed as follows:

Committee and subcommittee members	2,039
Langley Memorial Aeronautical Laboratory	1,975
Paris office of committee	2,539
Army Air Service	2,296
Naval Air Service, including Marine Corps	4,159
Manufacturers	4,384
Educational institutions	4,308
Bureau of Standards	1,019
Miscellaneous	9,184
Total distribution	31,903

The above figures include the distribution of 13,080 technical reports and 7,108 technical notes of the National Advisory Committee for Aeronautics. Three thousand two hundred and twenty-eight written requests for reports were received during the year in addition to innumerable telephone and personal requests and 15,497 reports were forwarded upon request.

REPORT OF THE COMMITTEE ON AERODYNAMICS.

ORGANIZATION.

The committee on aerodynamics is at present composed of the following members:

Dr. John F. Hayford, Northwestern University, chairman.
Dr. Joseph S. Ames, Johns Hopkins University, vice chairman.
Maj. T. H. Bane, United States Army.
Dr. L. J. Briggs, Bureau of Standards.
Commander J. C. Hunsaker, United States Navy.
Dr. Franklin L. Hunt, Bureau of Standards.
Maj. H. S. Martin, engineering division, McCook Field.
Prof. Charles F. Marvin, Chief Weather Bureau.
C. I. Stanton, Air Mail Service.
Prof. Edward P. Warner, Massachusetts Institute of Technology, secretary.
Dr. A. F. Zahm, United States Navy.

FUNCTIONS.

The functions of the committee on aerodynamics are as follows:

1. To determine what problems in theoretical and experimental aerodynamics are the most important for investigation by governmental and private agencies.
2. To coordinate by counsel and suggestion the research work involved in the investigation of such problems.
3. To act as a medium for the interchange of information regarding aerodynamic investigations and developments in progress or proposed.
4. The committee may direct and conduct research in experimental aerodynamics in such laboratory or laboratories as may be placed either in whole or in part under its direction.
5. The committee shall meet from time to time on the call of the chairman and report its actions and recommendations to the executive committee.

The committee on aerodynamics by reason of the representation of the various organizations interested in aeronautics is in close contact with all aerodynamical work being carried out in the United States. In this way the current work of each organization is made known to all, thus preventing duplication of effort. Also all research work is stimulated by the prompt distribution of new ideas and new results which adds greatly to the efficient conduction of aerodynamic research. The committee keeps the research workers in this country supplied with information on all European progress in aerodynamics by means of a foreign representative who is in close touch with all aeronautical activities in Europe. This direct information is supplemented by the translation and circulation of copies of the more important foreign reports and articles.

The Aerodynamic Committee has direct control of the aerodynamical research conducted at Langley Field, the propeller research conducted at Leland Stanford University under the supervision of Dr. W. F. Durand, and some special investigations conducted at the Bureau of Standards and at a number of the universities.

WIND TUNNEL.

The committee's wind tunnel at Langley Field has recently had several changes made in it which have considerably improved the steadiness of flow. The most important of these is a new electrical system consisting of a synchronous motor-generator set which furnishes power direct to the wind tunnel motor. The speed of the wind tunnel motor is kept at a constant value within ± 0.2 of a per cent by means of automatic voltage regulators. The air flow has also been considerably improved by placing a series of vanes around the end of the exit cone so that the air escapes radially. A wire type of balance is now used in this tunnel for all speeds between 30 and 60 meters per second.

It has long been felt that the tests made in the wind tunnel with a model varying much from the usual type are unreliable because of the uncertainty of the scale correction. For this reason the committee is now constructing at Langley Field a compressed-air wind tunnel with a throat diameter of 1.6 meters, a maximum speed of 25 meters per second, and a working pressure of 20 atmospheres. This wind tunnel will give a Reynolds number which is the same as for a full-sized airplane, and although the difficulties of supporting the model are great, the use of a comparatively low velocity and a high pressure have overcome the mechanical difficulties.

There are being constructed at the present time in the United States four other wind tunnels. At the Massachusetts Institute of Technology there are being erected a 1.25 meter and a 2.50 meter tunnel of the open-circuit type and with continuous throats. At McCook Field there is being constructed a high-speed 1.6 meter wind tunnel of the open-circuit type, which is designed for a velocity of 200 miles per hour. The Bureau of Standards at Washington is constructing a wind tunnel with a throat diameter of 3.25 meters. This wind tunnel is novel in that it is built in the open without any housing. The wind tunnel is well surrounded by trees and hills to prevent as far as possible the atmospheric conditions affecting the air flow.

The three-dimensional balance designed by Dr. A. F. Zahm for the Washington Navy Yard wind tunnel has proved very satisfactory. The weights of this balance are automatically actuated by electrically driven lead screws, and the time of making a test is much shorter than with other types of balances.

FREE FLIGHT.

The committee now has in use for aerodynamic research at Langley Field five airplanes; three *JN4H's*, one *VE-7*, and one Thomas-Morse *MB3*. The *JN4H* has been used by the committee extensively in experimental work, mainly because of its strength and the economy of operation. During the past year the flying time of the airplane has been 110 hours, representing 260 flights. Fifty-two per cent of the flying time has been used in actually making measurements in the air. No accidents of any kind have occurred with the committee's airplanes. One forced landing was made due to the sticking of the carburetor float during violent stunting, but the airplane was brought down without damage to itself or the instruments which it contained. Although complete airplanes have not as yet been constructed by the committee, a number of parts, such as wings, tail surfaces, etc., have been designed and constructed at Langley Field for use in free flight research.

INSTRUMENTS.

A number of new pieces of apparatus have been constructed for the wind tunnel, including a machine for forming plaster wings, a new micromanometer, a light balance for measuring the moments of control surfaces, and an instrument for measuring the rolling velocity of wings. It has become more and more evident as the discrepancies between free flight and model tests have been discovered, that it is necessary to produce in the wind tunnel a slip stream comparable with that on the full-sized airplanes. A very small flexible shaft has been developed which is able to drive the model airplane propeller up to speeds of 30,000 revolutions per minute, which corresponds to the normal speed of a full-sized propeller. The flexible shaft is so small that it disturbs the air flow inappreciably and in this respect is superior to an electric motor or a turbine.

It is realized that all free-flight data must be obtained by recording instruments, first, because events happen so rapidly that observations are difficult to make, and secondly, because the observer is under rather a nervous strain and can not take observations as accurately as he could in the laboratory. For this reason the committee has designed and constructed a considerable number of standardized recording instruments, electrically driven and synchronized, for taking records on interchangeable film drums. With these instruments the only duty of the observer is to change the drums at the end of the record, for the pilot can start and stop all of the instruments with a single switch. The following instruments have been constructed and used during the year:

(1) A new accelerometer more compact and accurate than the previous model.
(2) A recording air speed meter with a high natural frequency and small friction.
(3) A new model of a kymograph.

(4) A multiple manometer which will record on a moving film 30 simultaneous records of varying pressures. The natural frequency of this instrument is very high and the volume does not change appreciably with changes in pressure, which is a very important fact when recording pressures through long tubes.

(5) An instrument for recording angular velocities about a single axis.

(6) A control position recorder for three controls.

(7) A balance for measuring the forces on a trailing wing in flight.

The aeronautic instruments section of the Bureau of Standards has been engaged in an extensive program of research and development work on aircraft instruments in cooperation with the National Advisory Committee for Aeronautics, the Army, the Navy, and to a more limited extent with other Government agencies and private concerns. In addition to the experimental investigations and the development of new instruments a considerable amount of work has been carried out in connection with the routine testing of service instruments.

The investigation of the altitude effect on air speed indicators undertaken at the request of the National Advisory Committee for Aeronautics has been continued and extended. The experiments have been conducted in an improved wind tunnel with a 16-inch throat and mounted in one of the Bureau of Standards altitude chambers. With this apparatus valuable data have been obtained at speeds up to 100 miles per hour and under conditions of pressure and temperature corresponding to altitudes up to 30,000 feet.

Research concerning the action of diaphragms and Bourdon tubes undertaken at the request of the National Advisory Committee for Aeronautics has been continued with the purpose of determining the laws of deflection and of obtaining essential information of value in the design of instruments involving the use of diaphragms and Bourdon tubes.

A series of eight reports dealing with the various aeronautic instruments has been prepared for the National Advisory Committee for Aeronautics and will be found in the Seventh Annual Report.

At the request of the Army and the Navy, the development of the following instruments has been undertaken:

An improved aircraft sextant.
An improved compass.
An improved precision barometer.
A precision altimeter compensated for air temperature.
A precision barograph.
An improved rate of climb indicator.
An improved rate of climb recorder.
A combined statoscope and rate of climb indicator.
A synchronizing type ground speed indicator.
An astronomical position finder.
A horizontal angle indicator.
An improved centrifugal tachometer.
An air speed indicator for dirigibles.
A ballonet volume indicator for dirigibles.
Standard testing sets for field use.

Pursuant of the policy of following the latest developments in aeronautic instruments in foreign countries, a member of the aeronautic instruments section was detailed to investigate the recent developments in England, France, Italy, and Germany. This work was carried on in cooperation with the National Advisory Committee for Aeronautics representative in Europe and our military, naval, and commercial attachés, and much valuable information has been obtained.

A carbon pile tensiometer is being developed for the Navy which allows the accurate recording of tensions at a distance. An instrument has been devised by the Navy for the measurement of the ground speed of an airplane at frequent intervals of time on taking off or landing.

AEROFOIL TESTS.

During the past year the committee has conducted a large number of aerofoil tests in its 5-foot wind tunnel at Langley Field. The main object of these tests was to study the properties of thick aerofoils suitable for internal bracing. The tests were made at 35 meters per second, and in some cases as high as 60 meters per second as it was found that thick wings improve in efficiency with the speed more rapidly than thin wings. Some of the sections developed had at all angles a higher efficiency than the R. A. F. 15 section tested under the same conditions, and yet were more than three times as thick as that section in the center, while the maximum lift coefficients were approximately the same. A number of wings were tested which tapered in plan form, and it was found, contrary to expectations, that heavily tapered wings had the same center of pressure travel and practically the same efficiency as wings of uniform section.

The distribution of pressure was studied over 12 thick aerofoils of various types in order to determine the loading along the spars when the section varied along the span. A new method was devised for constructing pressure distribution models with comparatively little expense.

The effect of placing an aerofoil close to a flat surface representing the earth was thoroughly investigated both at the Massachusetts Institute of Technology and at the Washington Navy Yard. It was found that there was a remarkable increase in efficiency of the wing when close to a flat surface, which accounts for the fact that certain airplanes float for such long distances before landing.

Work has been continued in the McCook Field wind tunnel on various aerofoils at very high speeds, and a further study of vortex motion has been made.

Perhaps the most interesting work which has been carried out on aerofoils is that done by the committee in the testing of large aerofoils when suspended beneath a flying airplane. The aerofoil, constructed in the same way as an ordinary airplane wing of wood and fabric, is pulled up against the lower side of the fuselage in taking off, and when in the air is lowered down by means of a windlass to a distance of 20 or 30 feet or as far as is necessary to get out of the influence of the downwash. The magnitude of the resultant force is measured by a balance in the fuselage and the angle at which the wing trails back from the vertical measures the angle of the resultant. From these figures the lift and drag can be easily computed. At present only small wings of 6 feet span have been tested in this way, but it is evident from the great steadiness with which they trail beneath the airplane that accuracies probably as great as those obtained in the wind tunnel can be reached, although it is necessary to fly in smooth air for this kind of work. The results from the present apparatus although only of a preliminary character show such a good agreement with high speed wind tunnel tests of the same section that it is proposed to use a large bombing machine and trail wings of 30 feet span beneath it. Tests of this nature have not only the same Reynolds number, but also the same velocity, the same size, and the same amount of turbulence as the full-sized airplane, so that the results can be used by designers with perfect confidence.

A number of aerofoil sections have been tested, among which were several of the Göttingen series. The Washington Navy Yard tests check the Göttingen tests as closely as could be expected, the general types of the characteristic curves being very similar in every case. The Göttingen aerofoils tested were: Nos. *173*, *255*, *256*, and *322*.

Tests for scale effect have also been made on the *R. A. F. 15* and *R. A. F. 19* aerofoils.

STRUTS.

An interesting investigation has been made at the navy yard wind tunnel in Washington in the distribution of pressure over a strut. It is concluded that the total drag of the strut is the small difference between the upstream and downstream drags, so that a small error in measuring these will cause a huge error in the total.

STABILITY.

A very complete investigation has been made of the oscillations in flight of the *VE-7* and the *JN4H*, the latter airplane with a special tail plane to make it statically stable. The results on the whole are in poor agreement with the theory, due mainly, it is believed, to the fact that the oscillations are large, often over 60°, and that the slip stream has a considerable influence.

Considerable work has been done on static stability and it is becoming more and more evident that the aspect ratio of the tail plane has by far the greatest influence on the stability. It has also been found in actual flight that complete static stability may be obtained when the load is positive upon tail surfaces at all times. A study of the distribution of pressure over the tail surfaces of this surface in steady flight has given valuable information as to the functions of this surface in producing stability.

The lateral stability derivatives Y_v, L_v, and N_v have been determined in free flight for the *JN4H* and comparison has been made with the results from wind tunnel tests. On the whole the agreement is good, the discrepancies being mainly due to the influence of the slip stream and to the fact that in the model the control surfaces were assumed to be in a neutral position, whereas actually they were at a considerable angle.

A mechanical device has been constructed which will illustrate in every particular the dynamic and statical stability of an airplane. By the adjustment of weights the effect of changing the mass, the moment of inertia, the damping, etc., can be produced at will. As yet it has not been possible to obtain any quantitative value for stability with this instrument, but it is hoped that it may be used for quickly finding the stability properties of a new airplane from its known characteristics.

Tests have been made by the Navy on a series of balanced control surfaces with various types of balance. The characteristics of the type in which the axis is placed aft of the leading edge of the movable surface have been investigated at some length.

STRESSES IN FLIGHT.

The distribution of pressure was determined over the horizontal tail surfaces of a *JN4H* during all types of maneuver. In no case did the maximum loading on the tail exceed 6 pounds per square foot, and contrary to the usual expectations this load was in an upward direction. A theory has been devised which will give the loading on the tail surfaces in close agreement with the actual measurements.

The distribution of pressure over the rudder and fin have also been investigated on the same airplane and it was found that the heaviest loads occur in a roll where the loading may go as high as 10 pounds per square foot. It is interesting to notice from the standpoint of fuselage design that the maximum load on the horizontal tail surfaces, the maximum load on the rudder and fin, and the maximum load on the wings may all occur at the same time.

The recent development of very high speed airplanes has shown that very large unexpected loads may occur on the wing surface, several instances causing the stripping of the fabric or crippling of the trailing edge. A Thomas-Morse single seater which has a speed of over 160 miles an hour has been fitted up for measuring the distribution of pressure over the wing surfaces. It is hoped to determine the pressures both in steady flight and during violent maneuvering, and for this purpose the wings have been especially strengthened.

CONTROLLABILITY.

The measurement of and the design for controllability are very important problems and ones which have received but scant attention. In fact, the very definition of controllability is at the present time stated vaguely. The committee is now making an attempt to find some accurate quantitative means of measuring the controllability of various airplanes and to find the effect on controllability of various changes in control surfaces.

The desire for high speed has led many designers to eliminate the external bracing on the horizontal tail surfaces and for this reason a number of airplanes have been constructed with rather thick sections for the tail surfaces. Several airplanes of this type have been found by pilots to be extremely sluggish in responding to the controls; that is, for a certain range about the neutral position the controls have no effect. This condition was investigated in the wind tunnel on a tail plane of this type, and it was found that the elevator must be moved several degrees on either side of its neutral position before the force on the tail is appreciably changed, due to the fact that the elevator seemed to be in the shadow of the thicker portion of the tail surfaces and could have no effect until it was turned out into the free air stream.

The angular velocity and angular accelerations have been measured on a *JN4H* during all types of maneuver, in order to provide designers with data which will be of use in construction of airplanes.

The subject of control, especially lateral control, at low flying speeds has received some attention. It is evident, however, that different airplanes, although varying only slightly in external characteristics, vary tremendously in the amount of lateral control which they have at the stalling speed, and an explanation of this would be of great value. The Navy has recently devised an entirely new type of lateral control which in wind tunnel tests shows great promise.

AIRSHIPS.

Several types of external-pressure pads developed by the Navy have been tested upon the wings of an airplane at Langley Field in order to assure that such openings when cemented to the outside of the wing will give the same pressure reading as a flush hole. One type of pad has proved to be very successful. The possibilities have been considered of measuring the pressure over the surface of an airship during accelerated flight, and as yet no satisfactory method has been devised for entirely eliminating the rather large errors due to the forces acting upon the air column in the long connecting tubes which are necessary in this experiment. The investigation, however, has not been abandoned, and it is believed that the difficulties will be overcome.

Extensive tests have been made on two models of the rigid airship *ZR-1*. These tests were made on the hulls, bare and with six types of control surfaces.

Tests have been conducted at the navy yard wind tunnel in Washington on the effect of fineness, ratio, and length of parallel middle body on airship forms.

PROPELLERS.

Experiments have been conducted in the wind tunnel to measure the drag of various propellers under various degrees of yaw and with different amounts of braking. The drags of propellers are rather small so that the possibility of the safe vertical descent of the helicopter without power does not look very probable if the usual type of propeller is used. Tests have also been conducted upon a helicopter propeller having blades which are automatically set at a constant angle of attack by means of individual tail planes.

An extensive investigation has been carried out at Leland Stanford University on the properties of propellers at angles of yaw. The results look very promising in connection with the horizontal travel of helicopters, as a considerable horizontal thrust may be obtained with no more power than is required in ordinary flight.

BOMBS.

The Bureau of Standards has been conducting a very extensive investigation of bombs and projectiles not only in their 150-mile wind tunnel but also in a 12-inch air stream from a high-power compressor where speed can be obtained above the velocity of sound. Some very interesting conclusions have been reached in connection with stream lining at very high speeds.

REPORT OF THE COMMITTEE ON POWER PLANTS FOR AIRCRAFT.

ORGANIZATION.

The committee on power plants for aircraft is at present composed of the following members:

Dr. S. W. Stratton, chairman.
Henry M. Crane, Society of Automotive Engineers.
Harvey N. Davis, Harvard University.
Dr. H. C. Dickinson, Society of Automotive Engineers, acting secretary.
Leigh M. Griffith, Langley Memorial Aeronautical Laboratory.
Capt. G. E. A. Hallett, United States Army.
Lieut. Commander S. M. Kraus, United States Navy.
George W. Lewis, National Advisory Committee for Aeronautics.
C. I. Stanton, Air Mail Service.
J. G. Vincent, Packard Motor Car Co.

FUNCTIONS.

The functions of the committee on power plants for aircraft are as follows:

1. To determine which problems in the field of aeronautic power plant research are the most important for investigation by governmental and private agencies.
2. To coordinate by counsel and suggestion the research work involved in the investigation of such problems.
3. To act as a medium for the interchange of information regarding aeronautic power plant research in progress or proposed.
4. To direct and conduct research on aeronautic power plant problems in such laboratories as may be placed either in whole or in part under its direction.
5. To meet from time to time on call of the chairman and report its actions and recommendations to the executive committee.

By reason of the representation of the Army, the Navy, the Post Office, and the industry upon this subcommittee, it is possible to maintain close contact with the research work being carried on in this country and to exert an influence toward the expenditure of energy on those problems whose solution appears to be of the greatest importance, as well as to avoid waste of effort due to unnecessary duplication of research. For purposes of detailed consideration, the activities of this committee can be advantageously grouped under the following heads:

Fuel-injection engine.
Supercharging compressors.
Cooling problems.
Radiation problems.
Carburetion problems.
Ignition problems.
Fuels and combustion.
Lubricants and lubrication.
Performance characteristics.
New engine types.
Extension of laboratory facilities.

FUEL INJECTION ENGINE.

The development of the aeronautic type of fuel-injection engine is one of the most important problems involved in the future evolution of large aircraft. As previously noted, the especial importance of such a development to the Bureau of Aeronautics of the Navy Department has resulted in their financial support of an extended research into the problems involved, the work being performed at the National Advisory Committee for Aeronautics research laboratory at Langley Field. Research on this general problem naturally divides into two main groups, largely because of the difference in type of apparatus required.

The study of the fundamental characteristics of fuel sprays, produced by different forms of nozzles and under various pressures and temperatures, is essentially a matter for the physical laboratory. Apparatus has been developed with which successive photographs of a single fuel injection spray are taken at a photographic frequency of approximately 1,200 per second. These are taken full size in groups of 15 upon a film, the film being mounted on a rapidly rotating drum. The illumination is secured by the mechanically timed discharge of 15 condensers, the spark passing between magnesium points and the light being concentrated upon the spray by means of reflectors so placed that the illumination is by the dark-field method, thus insuring that only light which has been reflected or refracted by the fuel drops themselves can enter the camera lens.

The fuel injection spray is controlled by means of a specially designed cam-operated injection valve similar to the mechanism used upon stationary and marine fuel injection engines of the hydraulic injection type. The spray nozzle itself consists of a single opening in a nozzle plate, a set of such nozzle plates being available with holes varying in size from 0.004 to 0.024 inch. The most of the photographic study has been performed with nozzle openings to about 0.020 inch. The cam which operates the fuel injection valve is intermittently driven from a constant speed shaft, through one or more revolutions as desired, by means of a positive clutch of the general type used upon punch presses. This insures that any single injection is carried out at the same speed as in actual engine operation.

The fuel is supplied to the injection valve by a hand pump at any desired pressure up to 15,000 pounds per square inch. The injection takes place in a glass-walled chamber in which any desired air or nitrogen gas pressure up to 600 pounds per square inch may be obtained. The conditions therefore similate actual engine operation to a large extent, the element of high temperature being the only important factor neglected.

Studies have been made with water, light engine oil, and kerosene. Injection pressures up to 10,000 pounds and chamber gas pressures up to 150 pounds have been used. In addition to the series photographs on film, several hundred single photographs have been taken on glass plates, the series effect being secured by slightly altering the phase relation for each exposure. These latter are of good definition and depth, as the considerably increased amount of energy available for the single spark increased the intensity of illumination so greatly as to permit the camera lens to be stopped down to about one-sixteenth its former aperture.

In the case of the series records taken on film at the rate of 1,200 per second, the full development of the spray from the point at which the fuel first emerges from the nozzle occupies only three or four pictures, and the subsidence of the spray even less. Provision is therefore being made for considerably increasing the exposure frequency in order that the phenomena occurring during these two stages may be more thoroughly studied. Although the improved apparatus is not yet completed, it is quite evident from the work done that the frequency may be conveniently increased at least five times.

The work done to date has shown that no great difficulty will be experienced in producing photographs of such sharpness and depth that the characteristics of the spray are clearly shown and the spray development easily followed. It therefore only remains to secure similar photographs at higher speeds from sprays obtained with varying forms and sizes of nozzles, varying injection and spray chamber pressures, fuels or other liquids of various characteristics, and varying forms of cam opening and cam speed to enable the determination of the fundamental reasons for the differences in form, pulverization, penetration, and other characteristics. Much information has already been secured, although the investigation is still in its infancy.

The other group of the research activities on the fuel injection problems involves the application of the fundamental information obtained in the physical laboratory research to the actual operation of fuel injection engines in the dynamometer laboratory. In order to carry on this work to the best advantage, a very special single cylinder universal test engine has been designed and is being constructed. This engine is so arranged that the compression ratio can be changed throughout a wide range while the engine is running, as can also the opening and closing time and the lift of both inlet and exhaust valves. Each of these seven functions is controlled quite independent of the others, so that this engine is particularly well adapted to quickly determine the optimum adjustment for any condition of operation. The fuel injection devices to be applied are completely controllable in all their characteristics, and apparatus will be provided for measuring the important engine operation quantities, so that the results of tests on this equipment will provide complete data for the analysis and development of the high capacity and high speed fuel injection engine.

As the possibility of operating the present standard Liberty engine by some form of fuel injection system is attractive for some applications of that engine, work is also being carried on with a single cylinder Liberty which has been fitted with a special high compression piston and means for the application of various forms of fuel injection equipment. It is realized that the combustion chamber form is not well adapted to fuel injection, but it is believed that a specific power output and economy may be secured that is only slightly lower than with the standard Liberty.

SUPERCHARGING COMPRESSOR.

The Roots type of positive displacement blower as a compressor for supercharging aeronautic engines has been subjected to continual study throughout the year at the National Advisory Committee for Auronautics Research Laboratory at Langley Field. The original experimental machine has been in operation for a total time of approximately 75 hours, and tests have been made with it both as a separate unit and as mounted upon a Liberty engine. All of this work was done upon the dynamometer and very complete data was obtained of the characteristics of this device. The conditions were made to similate actual supercharging operation by connecting the suction of the compressor to a large depression tank in which the pressure was maintained at any desired value from atmospheric down to 6.5 pounds absolute.

In the case of the tests of the compressor alone, the discharge was direct to the atmosphere in the room and the compressor was directly driven by an electric dynamometer, so that very accurate power measurements were possible. Measurement of the air handled by the compressor was made by means of thin plate orifices conforming to the Durley standard, these orifices being placed at the entrance to a large chamber which in turn was connected to the depression tank through a control valve. The test performance of this compressor was very satisfactory. At a speed corresponding to normal engine speed, the overall efficiency compared to adiabatic compression was 73 per cent at a pressure ratio of 1.3 and 61 per cent at a pressure ratio of 2, these values being approximately 80 per cent of the maximum adiabatic efficiency which this type of compressor can possibly yield. The slip speed, or speed required to just maintain a given pressure ratio without discharge, was approximately 50 revolutions per minute at a ratio of 1.3 and 100 revolutions per minute for a ratio of 2, these low values resulting directly from the small clearances allowed.

Following the complete testing of the compressor alone, it was mounted upon a Liberty 12-cylinder aircraft engine, for which it had been designed, and tests made of the combined unit upon the dynamometer stand. When a receiver of 1.8 cubic feet capacity was placed next the supercharger in the air duct leading to the carburetors, the engine functioned well at all speeds, loads, and altitudes. As such a large receiver is extremely inconvenient to install in an airplane, it was deemed necessary to eliminate it from the final form of the apparatus. With a direct air duct connection, however, considerable difficulty was experienced due to resonance interference between the pressure impulses produced by the supercharger and the engine, this interference being so great at certain critical speeds as to prevent operation of the engine. After a number of experimental air duct arrangements had been tested, it was found that a small receiver immediately adjacent to the carburetor intakes had almost the same effect as a much larger receiver next the supercharger. Although the resonance interference has not been entirely eliminated, it has been confined to a small zone in an unimportant part of the speed range.

The following test figures are representative of the results which may be expected from service units of this type, when reasonably well maintained. At a normal engine speed and pressure ratio of 1.8 (approximately equivalent to an altitude of 16,000 feet), the supercharged unit gave within 11 per cent of its ground level power output, or within 12 per cent of the ground level power of a nonsupercharged engine. The test figures were corrected to the standard air temperature for that altitude and for the power increase due to the reduction of exhaust back pressure. This performance appears to be quite satisfactory, especially when compared to the 50 or 55 per cent power loss suffered by the nonsupercharged engine at that altitude.

The first experimental form of Root type supercharger will add something like 190 pounds to the total weight of a Liberty power plant, including the mounting and additional radiator, but it is believed that this can be reduced to under 150 pounds in subsequent models.

Following the completion of the dynamometer stand development, the supercharged engine is to be installed in a *DH-4* airplane and further tests conducted in free flight. A complete instrumental equipment will be fitted, in order that the flight test data shall be as comprehensive as possible.

Early in the year, some work was done with the positive gear driven centrifugal fan type of supercharging compressor, utilizing the apparatus built and partly developed by the American Expeditionary Forces in Paris during the last months of the war, but this work had to be laid aside on account of lack of personnel. The type shows considerable promise however, and it is the intention to again take it up at the earliest opportunity in order to definitely ascertain its value in comparison with the other types of superchargers which are more fully developed.

The engineering division of the Air Service has energentically continued its development of the General Electric exhaust turbine-driven centrifugal compressor and has built a number of units for experimental purposes. This type of supercharger is now a proved device, as is evidenced by its continuous use throughout the year with only minor changes. It has to its credit the world's record flight, reaching an indicated altitude of 40,800 feet. The engineering division is also developing the Sturtevant centrifugal blower type which is directly driven from the engine, but it has not as yet passed from the laboratory stage. They have also made a preliminary study of the gear driven centrifugal compressor of the heavy rotor type.

It is believed that the general problem of supercharging aeronautic engines to maintain power at altitude is perhaps next to the most important problem requiring immediate attention, and the committee's program calls for the energetic prosecution of research and development in this field.

COOLING PROBLEMS.

The problems incidental to the development of air cooled aviation engines of high performance are being studied in an experimental way at the McCook Field laboratory of the engineering division, Air Service. Much laboratory work of a more fundamental nature has also been carried on at the Bureau of Standards, the most of which is applicable to the radiation problem of the water cooled engine as well as to the direct air cooled type. It is hoped that it will be possible to concentrate increased research effort upon the problems of the air cooled engine, the importance of a satisfactory elimination of the radiator being well recognized by all.

New forms of radiator cores have been tested as they became available, and considerable progress has been made in the application of the laboratory research results to the logical design of radiators for specific installations. It is proposed to construct apparatus for the direct measurement of the air flowing through radiator cores in free flight when forming part of standard radiator installations on aircraft.

Several radiator cores of newer types, including a few specimens of the style finally adopted by the Air Service as a standard, were measured, and a report summarizing all the airplane radiator work done at the Bureau of Standards during the past four years has been prepared and is being published by the Bureau of Standards.

The Bureau of Standards is cooperating with the engineering division of the Army Air Service in a study of the fundamental relations between the heat removed from the hot metal of air-cooled cylinders and the power necessary to produce the air flow required for cooling. It is hoped that a number similar to the "figure of merit" used for airplane radiators can be determined for the ready intercomparison of air-cooled cylinder designs.

CARBURETION SYSTEMS.

Because of the excellent performance of the Maybach and B. M. W. engines under altitude conditions and the unique design of their carburetors, special investigations were made of the carburetors used on these engines. This work was done for the engineering division of the Army Air Service in the carburetor test plant of the Bureau of Standards. The results of this work have been collected in two reports, which it is hoped will be submitted to the committee for publication in the next annual report.

Two possible methods of inherent compensation of mixture ratio for altitude have been studied in the carburetor test plant of the Bureau of Standards. Both methods have given results which indicate that at full throttle a mixture ratio can be maintained independent of atmospheric pressure without aneroid control. Part throttle operation has as yet not been investigated.

During the course of the investigations in the altitude laboratory at the Bureau of Standards snow formation in the intake manifold was observed. This phenomena caused decidedly erratic and uncontrollable engine operation. As a similar phenomena could easily occur in actual flight, a short note on the subject was prepared and published by the committee as a technical note.

IGNITION PROBLEMS.

The routine testing of new forms of spark plugs and spark-plug insulators has been continued, both at the Bureau of Standards and at McCook Field. A gradual improvement of spark plugs has been noted, but much yet remains to be accomplished to insure the total elimination of spark,plug trouble. The experimental and mathematical investigation of the series gap has been continued, but final conclusions were not reached.

The program for the future provides for the continuance of routine tests of spark plugs and ignition systems generally, and also for the specific investigation of the effect of variation in ignition spark characteristics upon the engine performance.

Two reports on the theory of high tension magneto operation have been prepared by the Bureau of Standards and are being published by the committee. These reports are the result of experience gained in the magneto work previously carried out at the Bureau of Standards. One is an exact mathematical treatment and the other a more popular and nonmathematical treatment of the subject.

During the work on the high-compression engines in the altitude laboratory of the Bureau of Standards, it was noticed that the temperature of spark-plug electrodes was a major factor in determining the breakdown voltage of a given spark gap. A further investigation of this factor is being made in cooperation with the Army Air Service.

It has been observed at the Bureau of Standards that when an engine is operating on a very lean mixture on the verge of inflammability, the character of the ignition spark becomes important. Further investigation has shown that a very lean mixture ignited by a number or shower of sparks will miss fire less often than when ignited by a single spark. This subject is being further investigated in cooperation with the Army Air Service.

FUELS AND COMBUSTION.

The experimental investigation of compounded fuels has been continued by the Air Service at McCook Field and by the General Motors research laboratory at Dayton, Ohio. The value of such fuels for supercompressed engines or engines receiving their charge at a high temperature is thoroughly established. The investigation of compound fuels will be continued, as it is quite possible that their use may be obligatory in the high performance direct fuel injection engine, as well as in the high-compression carbureted engine.

The subject of the rate of flame propagation is under continuous experimental investigation, but has proved to be so complicated that it has not been possible as yet to draw definite conclusions from the work. This investigation is being carried on at the Bureau of Standards, and it is intended to devote an increased amount of attention to it during the coming year as an integral part of the general investigation of fuel characteristics.

Three independent methods for the laboratory measurement of reaction velocity in explosive gas mixtures have been developed at the Bureau of Standards. All the methods have been tried successfully with acetylene and illuminating gas, both of which have fairly well-known reaction velocities. These methods are, (1) the explosion of a mixture in a tube and either a photographic measurement of the rate of flame travel or the measurement of the energy liberated by means of a ballistic pendulum; (2) the measurement of reaction velocity by photography the contour of the inner core of a Bunsen flame; and (3) the photographic record of the combustion rate in a mixture inclosed in a spherical soap bubble and fixed at its center. A supply of carbon monoxide, which has a simple combustion reaction, has been obtained and it is planned to measure its rate of combustion by all three methods to establish their value, and then measure the combustion rates of hydrocarbon fuels.

The use of fuels of lower volatility has received considerable attention, more especially in connection with the development of the fuel injection engine. The greatly increased safety made possible by the substitution of such fuels for the present high volatility aviation gasoline, with the resulting indicated saving of lives and material, makes the subject one of the greatest possible importance. The program provides for the energetic prosecution of work upon this subject during the coming year.

LUBRICANTS AND LUBRICATION.

This subject has not received much attention. The program provided for the comprehensive study of the general subject of lubrication phenomena, with the object of determining the fundamental reasons for the unexplained differences in the lubricating value of oils which ordinary tests show to be quite similar. A lack of funds and personnel has, however, prevented carrying out this program, although it is hoped that the subject may be given proper attention during the coming year.

PERFORMANCE CHARACTERISTICS.

Although the work of determining the exact performance characteristics of existing engines does not definitely come under the classification of research, the Bureau of Standards has, by reason of its possession of ample altitude chamber equipment, carried out a number of performance tests of American and foreign engines for the double purpose of obtaining accurate information concerning the relative merits of the engines and also to determine calibration data which could be applied to the computation of the performance of aircraft in which these engines were subsequently fitted.

The laboratory work on a very extensive series of experiments in the altitude chamber of the Bureau of Standards on the effect of changes in compression ratio on power output and fuel consumption has been completed. The computation and analysis of the results is about 70 per cent completed, and a report giving the results of this work will be ready for publication in the next annual report. These experiments have included the effects of changes in mixture ratio, carburetor air temperature, and engine speed, as well as air pressure, and should be of great importance in the design of engines for aircraft service.

Two German engines, the 300-horsepower Maybach and the 185-horsepower B. M. W., have been tested in the altitude laboratory in cooperation with the engineering division of the Army Air Service. The results of these tests have been submitted to the committee for publication, and furnish valuable data for the comparison of the performance of aircraft engines of successful foreign design with similar American designs.

Much publicity had been given to the high average economy attained in service by these two engines. An analysis of the action of these carburetors gave a very reasonable explanation for this economy. This explanation was therefore incorporated in a technical note submitted by the Bureau of Standards and published by the committee.

NEW ENGINE TYPES.

The possibilities of the double-piston two-cycle fuel injection automatic ignition engine have been kept prominently in mind during the past year, although it is realized that the development of such an engine must await the results of research into the problems of high-speed fuel injection and the application of such information to the development of a form of fuel-injection device that will answer the requirements of aviation engines. The research work on fuel injection has been described under the heading of "Fuel injection engines." It is proposed to begin active development of such an engine as soon as the fuel-injection research has produced results of sufficient value to justify that step. The possibility of altering the present four-cycle carburetted and electrically ignited engine so as to operate upon some form of fuel injection is being considered, and some work has been done in this direction, although it is realized that the conditions imposed by the present form of cylinder design will greatly increase the difficulties.

The air-cooled radial engine is being developed by McCook Field and the Navy Department, single-cylinder experimentation being relied upon to determine the most suitable form of cylinder and valve design. Some thought has been given to the advantages of operating large air-cooled engines by means of fuel injection, and this matter will receive attention during the coming year.

The engineering division laboratory at McCook Field has encouraged the development of a barrel type water-cooled engine, in which the cylinders lie parallel to the shaft, and a 350-horsepower unit of this type is now being constructed for experimental purposes. The possibility of reduced weight, head resistance, and vibration makes this type of considerable interest. Its development will be further encouraged during the coming year.

The engineering division has completed the development of its 18-cylinder 700-horsepower engine of standard broad-arrow type, and now has in hand the development of a 1,000-horsepower unit of this same form. An experimental model of the latter is now undergoing tests and has given results which indicate that little real difficulty is to be expected in its final perfection.

The Bureau of Aeronautics of the Navy Department has been giving considerable attention to high-power engines of the six cylinder in line type, a 400-horsepower unit being at the present time in process of development and a 1,000-horsepower unit having been designed and tested in the single-cylinder form.

EXTENSION OF LABORATORY FACILITIES.

The dynamometer laboratory equipment at Langley Field has been completely installed and made available for use, although it has been necessary to use one of the larger dynamometers as a temporary power plant for the generation of direct current for the operation of the laboratory. Contrary to expectations, no funds became available during the year for the construction of a permanent dynamometer building, so that it has been necessary to continue in the more or less temporary shelter provided by a standard Army hangar. Recently a 250-kilowatt motor generator set has been installed and connected to the central station of a neighboring town, so that it no longer is necessary to operate the temporary power plant, except for emergency requirements. The collection of engineering, physical, and electrical instruments and equipment has been increased during the year, although much remains to be accomplished in this direction.

The equipment at the Bureau of Standards has been materially refined as the result of operating experience, but no new major items have been added. The same comment applies to the engine laboratory facilities of the engineering division, Air Service, at McCook Field.

REPORT OF COMMITTEE ON MATERIALS FOR AIRCRAFT.

Following is a statement of the organization and functions of the committee on materials for aircraft:

ORGANIZATION.

Prof. Charles F. Marvin, chairman.
Dr. G. K. Burgess, Bureau of Standards, vice chairman.
Mr. Henry A. Gardner, Institute of Industrial Research.
Prof. George B. Haven, Massachusetts Institute of Technology.
Commander J. C. Hunsaker, United States Navy.
Mr. A. M. Hunt, American Magnesium Corporation.
Dr. Zay Jeffries, Aluminum Co. of America.
Mr. J. B. Johnson, Engineering Division, Air Service.
Prof. E. P. Warner, Massachusetts Institute of Technology.
Dr. Carlile P. Winslow, Forest Service.
Prof. H. L. Whittemore, Bureau of Standards, acting secretary.

FUNCTIONS.

1. To aid in determining the problems relating to materials for aircraft to be experimentally attacked by governmental and private agencies.

2. To endeavor to coordinate, by counsel and suggestion, the research and experimental work involved in the investigation of such problems.

3. To act as a medium for the interchange of information regarding investigations of materials for aircraft, in progress or proposed.

4. The committee may direct and conduct research and experiment on materials for aircraft in such laboratory or laboratories, either in whole or in part, as may be placed under its direction.

5. The committee shall meet from time to time on call of the chairman and report its actions and recommendations to the executive committee.

The committee on materials for aircraft, through its personnel acting as a medium for the interchange of information regarding investigations on materials for aircraft, is enabled to keep in close touch with research in this field of aircraft development.

Much of the research, especially in the development of light alloys, must necessarily be conducted by the industries interested in the particular development, and both the Aluminum Company of America and the American Magnesium Corporation are represented on the committee. In order to cover effectively the large and varied field of research on materials for aircraft three subcommittees were formed, as follows:

Subcommittee on metals (Dr. G. K. Burgess, chairman).
Subcommittee on woods and glues (Prof. H. L. Whittemore, chairman).
Subcommittee on coverings, dopes, and protective coatings (Mr. Henry A. Gardner, chairman).

Most of the research in connection with the development of materials for aircraft is financed directly by the Bureau of Construction and Repair of the Navy Department and the engineering division of the Army Air Service.

The Bureau of Construction and Repair not only conducts research at its aerodynamical laboratory at the Washington Navy Yard and at the naval aircraft factory in Philadelphia, but also apportions and finances research problems to the Bureau of Standards, the Langley Memorial Aeronautical Laboratory, the Institute of Industrial Research, and the Forest Products Laboratory.

SUBCOMMITTEE ON METALS.

Streamline wire.—This subcommittee has devoted much time to the preparation of a standard specification for the purchase of streamline stay wire similar to the Navy Specification No. 61. The first specification was issued in blue print form, Memo VII-1-18, to the members of the committee and others interested for criticism and suggestions.

This specification was revised and corrected in Memo VII-1-18A and after considering the criticisms of the largest manufacturers of these streamline wires in this country the committee is in a position to make a final report to the committee on materials for aircraft.

Due to the possibility of fatal accidents from the failure of a single stay wire on an airplane in flight, this subcommittee feels that only the best obtainable material should be used and that rigid inspection is necessary. For this reason provision is made in the specifications to insure a uniform high quality of material and a uniform treatment of each lot submitted for inspection so that the samples submitted to physical tests shall be representative of the lot from which they are taken. As an additional safeguard each wire is required to be submitted to a proof load within the elastic limit of the material.

The specifications contain a very carefully prepared series of sizes for the streamline sections having areas increasing in a geometrical series.

The allowable variations in dimensions were given careful consideration and the values recommended are believed to be those which will give wires which will be entirely satisfactory in use and not make the cost excessive.

The thread proposed for the terminals was the medium fit regular of the fine thread series recommended by the National Screw Thread Commission.

For protection of the wires from corrosion zinc plating was found to give the best results but spar varnish could be substituted.

This subcommittee has carefully considered the general subject of metals for aircraft and devoted all its energies to the investigation of those which appeared to be of the greatest importance. The possibilities in this field are very great and the facilities for fundamental research, particularly on the light alloys, should be greatly increased if this country is to undertake in quantity the development of either commercial or military all-metal aircraft.

Steel.—The fact that steel is the backbone of our material civilization with the vast amount of accumulated experience in regard to its manufacture and use, makes it highly desirable that its possibilities for use in aircraft be fully developed. It is low in cost and its resistanec to corrosion and fatigue, often the cause of failures, is fairly well known from experience supplemented by the results of laboratory experiments.

Steel strip has been produced which after heat treatment by the maker is formed and fabricated for aircraft parts. The heat treatment of thin steel sheets in this country is now impossible on a commercial scale and should be developed if this material is to be used for aircraft, automobile and other uses.

Prof. Moore has conducted at the University of Illinois for the National Research Council a series of fatigue tests on a large number of specimens of iron and steel. The specimens were tested in rotary beam machines of the Farmer type and in other type fatigue testing machines. Prof. Moore also used the thermometric method of determining the endurance limit. The preliminary reports indicate that there is a definite endurance limit which is proportional to the ultimate strength of the material.

An electrical method of heat testing long tubes of alloy steel has been perfected by Smead & Co. This material can be used in fuselage construction.

Light alloys.—Of the metals having a low specific gravity and comparatively high strength, the aluminum alloys similar to duralumin have been most generally used. At present this material can be obtained in the United States in many forms with the exception of tubes.

The alloys of magnesium are attracting attention due to their very light weight. Many of them have sufficient strength for many purposes but their resistance to corrosion must be more accurately known before they can be used with confidence.

These alloys have a wide field of usefulness particularly in aircraft, and the effect of variations in composition or in manufacture should be investigated and made available to all those interested. It is probable that alloys much more valuable than any known at present may be the result of properly directed research.

The methods of welding the light alloys as well as steel needs careful study and it is possible that other methods of joining parts may be largely replaced by welding.

Recent failures of metal aircraft structures show the need for laboratory investigations, not only on the materials, but also on the structural parts made from them. It is highly desirable to test full size girders, beams, and struts under the loading for which they are designed.

The effect of vibration on these structures may prove to be of great importance and should receive careful consideration.

The Bureau of Standards is continuing for the Bureau of Aeronautics, Navy Department, the tests on the corrosion of aluminum and its alloys in sea water and with various protective coatings, and unprotected specimens. Of the protective coatings the most promising seemed to be a light weight coating of varnish or oil. A coating of spar varnish remained for about ten months before scaling, and linseed oil gave good results for about a year. The test on basic, neutral and acid pigments indicate that there is no corrosion with any of the pigments after six months' exposure. The pigment coating has the disadvantage of being very high in weight as compared with the oil and varnish.

The Bureau of Construction and Repair, Navy Department, and the Air Service engineering division have both conducted extensive experiments as to the best material for the construction of gasoline tanks and fittings. The results of the tests of the effects of airplane fuels, dopes and doped fuels on the materials in the fuel system indicate that aluminum alloys are the least affected by the corrosive action of the fuels. Forged duralumin pipe fittings have been used and the aluminum alloy fuel tank proved superior to copper, tin, or terneplate as resisting the corrosive action of the fuel.

Considerable progress has been made in welding duralumin sheet in the construction of tanks and an aluminum solder has now been obtained that is satisfactory both for aluminum and aluminum alloys.

SUBCOMMITTEE ON WOODS AND GLUES.

Most of the research in the development of woods and glues for aircraft construction is carried on at the Forest Products Laboratory, Madison, Wis.

The problems studied include the properties of the woods of the United States and the conditions under which they are grown to secure the best results, the drying of the material, and methods of preventing decay, as well as the strength of structures made from wood, such as veneer, airplane wing ribs, etc. The development of a glue for joints in wood has been given a great deal of attention and the most favorable conditions of temperature, pressure, etc., have been determined. Waterproof glues are very desirable for aircraft construction and satisfactory glues of this type have been found.

Many problems for the Bureau of Construction and Repair of the Navy Department have been undertaken, such as the strength of screw fastenings and the making and testing for strength of structural parts of seaplanes and other aircraft.

The impact resistance of wood is an important property of this material in many cases, especially in airplanes. Many "crashes" are believed to be due to "brashness" of the wood in wing beams, and it seems desirable to give more importance to this subject. In addition to impact tests on small specimens, which have assumed considerable importance in England, it may be necessary to test full-size wings under conditions which approximate those found in service.

Very few tests of the fatigue resistance of woods have been made, but experience shows that they vary greatly in this respect. Certain woods, such as hickory for example, are found to be the best for the spokes of carriage wheels. There is little doubt that laboratory tests of fatigue would be of great assistance in selecting woods for aircraft construction which would secure the greatest safety with the least weight.

In the development of waterproof glues, the Forest Products Laboratory have obtained emulsions of animal glue and rubber in benzine. This glue may be more water resistant than animal glue. Tests have also been made with a casine glue which had been rendered insoluble by a treatment with formaldehyde. This glue was made under most favorable conditions and the results of tests show that it became soft and pliable after soaking in water for 11 days.

The indications are that this is the best we can expect of the water-resisting properties of casine glues.

A study has been made of the gluing pressure and temperatures to obtain the best results. Tests were made with three different glues and pressure of 25, 50, 150, 400, and 600 pounds per square inch. The results indicate that the quantity of glue spread and the exposure of the coated laminations appear to have a good deal to do with the amount of pressure necessary to obtain good joints. Medium and high pressures gave the best results.

From the preliminary tests of heating the wood before applying the glue results seem to indicate that warm wood and room give better results when low pressures are used.

The investigation by the Forest Products Laboratory for the Navy Department on the influence of internal stresses in laminated construction has been completed. The investigation covers three sources of internal stresses namely, the combination of plain-sawed and quarter-sawed material in the same construction, the gluing together of laminations of different moisture contents, and the gluing together of laminations of different densities. Nine species of wood were studied. The outstanding feature of the investigation is the decrease in magnitude of internal stresses with time and there is a strong indication that internal stresses die out under constant uniform atmospheric conditions.

Problems under way and not completed at the Forest Products Laboratory include a study of the influence of atmospheric and manufacturing conditions on airplane propellers, moisture resistant coatings, use of plywood in wing beams, study of torsion in box beams, and the design of beams for cantilever wings.

SUBCOMMITTEE ON COVERINGS, DOPES, AND PROTECTIVE COATINGS.

The Bureau of Aeronautics, Navy Department, has continued the investigation through the assistance of H. A. Gardner and the Bureau of Standards in developing a substitute for gold beater's skin for use with gas cells for rigid airships and possibly on the envelope of nonrigid airships. The films used include viscose, treated cellulose, gelatin compositions, casein, nitrocellulose, cellulose acetate, rubber, and tung oil. These have been tested singly and in combinations to determine permeability. The test results on certain of the films indicate that a gold beater's skin substitute is entirely possible.

Exposure tests of all specimens are to be made and provision is to be made by mechanical means to cause flexure of the film and duplicate service conditions.

The problem of obtaining a cheaper aircraft dope is being investigated by both the Army and Navy Air Services. The supplies of acetate dope, which was made during the war, are very limited and as the formula contains patented constituents the dope is very expensive.

TECHNICAL PUBLICATIONS OF THE COMMITTEE.

The committee on publications and intelligence has recommended the publication of 22 technical reports to be included in the seventh annual report. A summary of the technical reports published in the seventh annual report follows. The reports cover a wide range of subjects on which research has been conducted under the surveillance and cognizance of the various subcommittees, each report being approved by the subcommittee interested and recommended for publication to the executive committee. The technical reports presented represent fundamental research in aeronautics carried on at different aeronautical laboratories in this country, including the Langley Memorial Aeronautical Laboratory, the aeronautical laboratory at the Washington Navy Yard, the Bureau of Standards, and the Leland Stanford Junior University.

Considerable technical information is obtained by the committee that is of immediate interest to those interested in experimental and research problems in connection with aeronautics. To make this information immediately available, the National Advisory Committee for Aeronautics has authorized the committee on publications and intelligence to issue a series of "Technical Notes." In accordance with this authorization, the committee has issued 35 technical notes on subjects that were of immediate interest not only to research laboratories but also to airplane manufacturers. A list of the technical notes issued during the year follows the general summary of the technical reports.

The first annual report of the National Advisory Committee for Aeronautics contained technical reports Nos. 1 to 7; the second annual report, Nos. 8 to 12; the third annual report, Nos. 13 to 23; the fourth annual report, Nos. 24 to 50; the fifth annual report, Nos. 51 to 82; the sixth annual report, Nos. 83 to 110, and since the preparation of the sixth annual report the committee has issued the following technical reports, Nos. 111 to 132.

Report No. 111, entitled "The Variation of Aerofoil Lift and Drag Coefficients with Changes in Size and Speed," by Walter S. Diehl, Bureau of Construction and Repair, United States Navy.—This report contains the results of an investigation into the effect of changes in size and speed upon aerofoil lift and drag coefficients. Certain empirical limitations to the interchangeability of v and l in the general equation of fluid resistance are pointed out and the existing methods of correcting for scale are criticized.

New methods of correcting for scale by means of simple formulae are derived and checked by comparison with test results. The drag coefficient at any given angle of attack within the range of steady flow is found to vary according to the expression

$$Dc_2 = Dc_1 - Dc_0 \quad 1 - \left[\left(\frac{v_2\ l_2}{v_1\ l_1} \right) \right]$$

Where Dc_2 = Drag coefficient at $v_2\ l_2$

Dc_1 = Drag coefficient at $v_1\ l_1$

and Dc_0 = Minimum drag coefficient at $v_1\ l_1$

Under similar conditions the lift coefficient is found to vary according to the expression:

$$Lc_2 = Lc_1 + .057 \log_{10} \frac{v_2\ l_2}{v_1\ l_1}$$

Where Lc_2 = Lift coefficient at $v_2\ l_2$

Lc_1 = Lift coefficient at $v_1\ l_1$

The applications and limitations of the above formulae are discussed and it is recommended that they be checked by special tests extending over a wide range of $v\ l$.

Report No. 112, entitled "Control in Circling Flight," by F. H. Norton and E. T. Allen, Langley Memorial Aeronautical Laboratory.—This investigation was undertaken by the National Advisory Committee for Aeronautics at the Langley Memorial Aeronautical Laboratory for the purpose of developing instruments that would record the forces and positions of all three controls, and to obtain data on the behavior of an airplane in turns. All the work was done on a standard rigged *JN4H* (airplane No. 2 of National Advisory Committee for Aeronautics, Report No. 70). It was found that the airplane was longitudinally unstable and nose heavy; that it was laterally unstable, probably due to too little dihedral; and that it was directionally unstable, due to insufficient fin area, this last being very serious, for in case of a loss of rudder control the airplane immediately whips into a spin from which there is no way of getting it out. On the other hand, it was found possible to fly quite satisfactorily with the rudder locked, and safely, though not so well, with the ailerons locked. The value of Y_v was obtained in free flight, and when the effect of the propeller was subtracted, the agreement with the model test was excellent, but with the propeller revolving at 1350 the value of Y_v was nearly doubled. The value of L_v and N_v were little affected by the slip stream, but their values do not agree with the model test.

Report No. 113, entitled "Tests on Air Propellers in Yaw," by W. F. Durand and E. P. Lesley, Leland Stanford University.—This report contains the results of tests to determine the thrust (pull) and torque characteristics of air propellers in movement relative to the air in a line oblique to the line of the shaft, and specifically when such angle of obliquity is large, as in the case of helicopter flight with the propeller serving for both sustentation and traction.

Report No. 114, entitled "Some New Aerodynamical Relations," by Max M. Munk, National Advisory Committee for Aeronautics.—This report contains three new relations extending the modern theory of aeronautics, intended to be applied in some later papers. They deal with phenomena in a frictionless fluid.

The first part contains a relation between the power absorbed by an aerofoil and the power absorbed by a propeller. In the second part the exactness of the ordinary formula for the induced drag of an aerofoil is examined and the error is determined.

In the third part the author shows that for the calculation of the air forces on bodies of considerable volume the imaginary sources and sinks equivalent to the flow around the body can be used in the same way as vortices are used for the calculation of lift and induced drag of wings.

Report No. 115, entitled "Bending Moments, Envelope and Cable Stresses in Nonrigid Airships," by C. P. Burgess, Bureau of Aeronautics, United States Navy.—No simple but comprehensive method of calculating the principal stresses in the envelope of a nonrigid airship has hitherto been described and published in the English language. The present report describes the theory of the calculations and the methods which are in use in the Bureau of Aeronautics, United States Navy. The principal stresses are due to the gas pressure and the unequal distribution of weight and buoyancy, and the concentrated loads from the car suspension cables.

The second part of the report deals with the variations of tensions in the car suspension cables of any type of airship, with special reference to the rigid type, due to the propeller thrust or the inclination of the airship longitudinally.

Report No. 116, entitled "Applications of Modern Hydrodynamics to Aeronautics," by L. Prandtl, Göttingen Laboratory.—The report gives rather briefly in Part I an introduction to hydrodynamics which is designed to give those who have not yet been actively concerned with this science such a grasp of the theoretical underlying principles that they can follow the subsequent developments. In Part II there follows a separate discussion of the different questions to be considered, in which the theory of aerofoils claims the greatest portion of the space. The last part is devoted to the application of the aerofoil theory to screw propellers.

Dr. Prandtl at the request of the National Advisory Committee for Aeronautics has used the same symbols in the formulæ as are used in Dr. Prandtl's German papers. These symbols are for the most part familiar to readers of the Technische Berichte. A table giving the most important quantities is at the end of the report. A short reference list of the literature on the subject and also a table of contents are added.

Report No. 117, entitled "The Drag of Zeppelin Airships," by Max M. Munk, National Advisory Committee for Aeronautics.—This report is a discussion of the results of tests with Zeppelin airships, in which the propellers were stopped as quickly as possible while the airship was in full flight. In this paper the author refers to the theory involved in these tests and calls attention to one scientifically interesting fact which can be derived from the tests and which has not yet been noted.

The most important general question concerning the tests is, of course: Does the negative acceleration of an airship with stopped propellers supply proper data for determining the drag of the airship when in uniform flight? This can not be absolutely answered in the affirmative, the two phenomena not being identical in principle. It is believed, however, that in this particular case the agreement is sufficient and that the data obtained from the test are the true quantities, or, at least, the approximate quantities wanted.

Report No. 118, entitled "The Pressure Distribution Over the Horizontal Tail Surfaces of an Airplane," by F. H. Norton, Langley Memorial Aeronautical Laboratory.—This work was undertaken by the National Advisory Committee for Aeronautics at the request of the Bureau of Construction and Repair of the United States Navy in order to determine as completely as possible the distribution of pressure over the horizontal tail surfaces of an airplane, and to analyze the relation of this pressure to the structural loads and the longitudinal stability. The investigation is divided into three parts, of which this is the first. The first part of the investigation is for the purpose of determining the pressure distribution over two horizontal tail surfaces in uniform free flight; the second part to conduct tests of similar tail planes in the wind tunnel; and the third part to determine the pressure distribution on the horizontal tail surfaces during accelerated flight on the full-sized airplane.

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The general method used in this part of the investigation consists in determining the separate pressures at a large number of points on the tail surfaces of a *JN4H* airplane, by connecting small holes, opening on the tail surface, to the tubes of a multiple liquid manometer, which simultaneously measures the total number of pressures on one-half of the tail surface. The pressures are recorded by photographing the multiple manometer with an automatic camera which takes an exposure at each condition of air and engine speeds.

The tests in uniform free flight gave the following results:

1. Under no condition did the average tail load exceed 2.3 pounds per square foot.
2. The highest local load on the tail of the *JN4H* was 11 pounds per square foot.
3. The highest local load on the special tail was 25 pounds per square foot.
4. The torque exerted by the tail about the X-axis ranged from +1,200 inch-pounds (in the direction of the propeller rotation) to −1,600 inch-pounds.
5. The sealing of the crack between the elevator and tail plane has no appreciable effect on the distribution of pressure.
6. The inversion of the standard tail plane (flat surface up) gives a more uniform distribution of pressure as well as improving the stability.
7. The airplane was very stable with the special tail of high aspect ratio even with a center of gravity coefficient of 0.37.
8. The center of pressure travel on the wings, as determined by the integrated tail load, is farther forward than on the corresponding model.

Report No. 119, entitled "The Pressure Distribution Over the Horizontal Tail Surfaces of an Airplane—II," by F. H. Norton and D. L. Bacon, Langley Memorial Aeronautical Laboratory.—This investigation was undertaken by the aerodynamic staff of the National Advisory Committee for Aeronautics at Langley Field in order to determine whether the results obtained upon model tail surfaces can be used to accurately predict loads upon the full-sized tail; and also to find the distribution of load when large elevator angles are used, as the loads from such angles can not be obtained readily in free flight. The method consisted in using a metal horizontal tail surface inside of which small air passages, connecting with a series of holes in the surface, led the pressure off from the tail in rubber tubes. In this way the pressure at each of these holes was measured by a manometer at several angles of attack and several elevator settings. The results show that the model tests give a loading which is equivalent to the loading under similar conditions in the full-sized airplane and that the manner of distribution is quite similar in the two cases when there is no slip stream.

Report No. 120, entitled "Practical Stability and Controllability of Airplanes," by F. H. Norton, Langley Memorial Aeronautical Laboratory.—Thz effect of the characteristics of an airplane or balance, stability, and controllability, based on free flight tests, is discussed particularly in respect to the longitudinal motion. It is shown that the amount of longitudinal stability can be varied by changing the position of the center of gravity or by varying the aspect ratio of the tail plane, and that the stability for any particular air speed can be varied by changing the camber of the tail plane. It is found that complete longitudinal stability may be obtained even when the tail plane is at all times a lifting surface. Empirical values are given for the characteristics of a new airplane for producing any desired amount of stability and control, or to correct the faults of an airplane already constructed.

Report No. 121, entitled "The Minimum Induced Drag of Aerofoils," by Max M. Munk, National Advisory Committee for Aeronautics.—The "Minimum Induced Drag of Aerofoils" helps to explain the phenomenon of flight. It contains some theorems concerning the arrangement of airplane wings which are of considerable practical interest. In particular, it shows the theoretical reasons for the decrease of drag which accompanies all increase in the aspect ratio or lateral extension of a wing. The efficiency of a given arrangement of wings may be calculated from the formulæ derived in this paper.

Report No. 122, entitled "Preliminary Experiments to Determine Scale and Slip Stream Effects on a one-twenty-fourth Size Model of a *JN4H* Biplane," by D. L. Bacon, Langley Memorial Aeronautical Laboratory.—This work was undertaken at the Langley Field Aerodynamic Laboratory of the National Advisory Committee for Aeronautics to obtain results on a small model of a complete airplane which might be used for comparison with corresponding tests made in full flight. Somewhat similar tests have been previously made at various other laboratories; but as certain discrepancies exist between corresponding tests in different tunnels, it has been deemed advisable to obtain a direct comparison for this particular installation.

The present work covers tests on a one-twenty-fourth scale model at speeds varying from 6.7 m/sec. (15 m. p. h.) to 40.2 m/sec. (90 m. p. h.). A slip stream correction has been obtained by the use of a small belt-driven propeller mounted in front of the model, and force coefficients thus obtained are compared with the measurements of the same forces made in full flight on a geometrically similar airplane.

This report gives lift, drag, and longitudinal moment values obtained in tests of a particularly accurate model over a wide range of speeds. A measure of the slip stream corrections on lift and drag forces was obtained by the use of a power-driven model propeller. Measurements were also made of forces and longitudinal moments for all angles from 0° to 360°.

Report No. 123, entitled "Simplified Theory of the Magneto," by F. B. Silsbee, Bureau of Standards.—This paper contains part of the results of ignition investigations being made for the National Advisory Committee for Aeronautics at the Bureau of Standards, and described a type of circuit which has been found useful for representing the action of the high-tension magneto. While this equivalent circuit is relatively simple, and consequently can be used as a basis for deriving definite mathematical formulas for induced voltages and similar quantities, it has been found experimentally to correspond quite closely in its performance with the highly complicated electrical circuits of an actual magneto. In the paper formulas are given for the voltage induced in the secondary under various conditions of operation, and a number of numerical examples are worked out showing the application of the equation to a variety of practical problems.

Report No. 124, entitled "Aerodynamic Characteristics of Aerofoils—II," by the National Advisory Committee for Aeronautics.—This collection of data on aerofoils has been made from the published reports of a number of the leading aerodynamic laboratories of this country and Europe. The information which was originally expressed according to the different customs of the several laboratories is here presented in a uniform series of charts and tables suitable for the use of designing engineers and for purposes of general reference.

It is a well-known fact that the results obtained in different laboratories, because of their individual methods of testing, are not strictly comparable even if proper scale corrections for size of model and speed of test are supplied. It is, therefore, unwise to compare too closely the coefficients of two wing sections tested in different laboratories. Tests of different wing sections from the same source, however, may be relied on to give true relative values.

The absolute system of coefficients has been used, since it is thought by the National Advisory Committee for Aeronautics that this system is the one most suited for international use, and yet is one for which a desired transformation can be easily made. For this purpose a set of transformation constants is included in this report.

Each aerofoil section is given a reference number, and the test data are presented in the form of curves from which the coefficients can be read with sufficient accuracy for design purposes. The dimensions of the profile of each section are given at various stations along the chord in per cent of the chord, using as datum the line shown on the curves. The shape of the section is also shown in reasonable accuracy to enable one to more clearly visualize the section under consideration, together with its characteristics.

The authority for the results here presented is given as the name of the laboratory at which the experiments were conducted, with the size of the model, wind velocity, and date of test.

Report No. 125, entitled "General Classification of Instruments and Problems, Including Bibliography," by Mayo D. Hersey, Bureau of Standards.—This report is Section I of a series of papers, comprising a general report on aeronautic instruments, published as Technical Reports

Nos. 125 to 132, inclusive, which contain the results of investigations relating to aeronautic instruments undertaken at the Bureau of Standards under research authorizations formulated and recommended by the subcommittee on aerodynamics and approved by the National Advisory Committee for Aeronautics.

As authorized by the committee on aerodynamics, these reports include a complete account of the status of aeronautic instruments at the end of the war and cover the subject in detail up to the beginning of the year 1920. Nearly a year and a half has been required for the actual preparation of the manuscripts, which represent the cooperative effort of seventeen individual authors, many of whom have left Government service. Report No. 132, by Dr. F. L. Hunt, now chief of the aeronautic instruments section of the Bureau of Standards, serves to bridge this gap by giving a brief statement of recent developments. The bibliography also has been kept complete up to the moment of going to press.

Technical Reports Nos. 126 to 131, inclusive, contain a systematic, illustrated description of American, British, French, Italian, Swiss, Dutch, Danish, Austrian, and German aircraft instruments, together with methods of testing developed by the Bureau of Standards, and brief statements of investigation results. In compiling the material for these reports, separate papers have been written by experts on the respective types of instruments, as, for example, altimeters, tachometers, or oxygen apparatus.

Subjects which are common to instruments in general are treated in this report. Throughout the series of reports emphasis has been placed on the description of successful types of instruments and the exposition of fundamental scientific principles, while the space devoted to investigations and developments of transitory interest has been reduced to a minimum. In this way it is expected that the reports will be of permanent value for reference.

This report is intended as a technical introduction to the series of reports on aeronautic instruments. It presents a discussion of those subjects which are common to all instruments. In the first place, a general classification is given, embracing all types of instruments used in aeronautics. The arrangement of information dealing with these various instruments throughout the reports is then briefly indicated as a guide to the reader. Finally a classification is given of the various problems confronted by the instrument expert and investigator. In this way the following groups of problems are brought up for consideration: First, problems of mechanical design; second, human factor; third, manufacturing problems; fourth, supply and selection of instruments; fifth, problems concerning the technique of testing; sixth, problems of installation; seventh, problems concerning the use of instruments; eighth, problems of maintenance; ninth, physical research problems. This enumeration of problems which are common to instruments in general serves to indicate the different points of view which should be kept freshly in mind in approaching the study of any particular instrument.

Report No. 126, entitled "Altitude Instruments," is made up of four parts. Part I on "Altimeters and Barographs," discusses briefly barometric altitude determinations with the view of explaining the methods of calibrations of altimeters and barographs used by various nations. A detailed description is given of all the principal types used and a discussion is given of results of investigations carried on at the Bureau of Standards during the past four years.

Part II, "Precision Altimeter Design." In this report the authors first developed a theory of aneroid design and then checked the results by experiments on an instrument constructed according to the theory. It was found that the most difficult error to eliminate or correct in an aneroid barometer is elastic lag or time effect.

Part III, "Statoscopes and Rate of Climb Indicators." The authors have made a detailed study of statoscopes, and for convenience, statoscopes are divided into two types, mechanical or diaphragm and bubble. The leak type rate-of-climb indicators receive major consideration in the discussion on calibration and tests.

Part IV, "Aerographs and Strut Thermometers." This paper contains a description of the principal types of thermometers and other aerographic instruments, including direct and distance reading strut thermometers. The paper concludes with a discussion of methods of testing and performance characteristics.

Report No. 127, entitled "Aircraft Speed Instruments," is presented in three parts. Part I, "Air Speed Indicators," Part II, "Testing of Air Speed Meters," and Part III, "Principles of Ground Speed Measurement."

Part I contains a discussion and description of the various types of air speed measuring instruments. The authors then give general specifications and performance requirements with the results of tests on air speed indicators at the Bureau of Standards.

Part II reports methods and laboratory apparatus used at the Bureau of Standards to make static tests. Methods are also given of combining wind tunnel tests with static tests. Consideration is also given to free flight tests.

Part III discusses the problem of finding suitable methods for the purpose of measuring the speed of aircraft relative to the ground. As yet no entirely satisfactory solution has been found.

Report No. 128, entitled "Direction Instruments." This report is divided into five parts, as follows:

Part I, "Inclinometers and Banking Instruments" points out the adequacy of a consideration of the steady state of gyroscopic motion as a basis for the discussion of displacements of a gyroscope mounted on an airplane, and develops a simple theory on this basis. Principal types of gyroscopic inclinometers are described and requirements stated.

Part II, "A New Type of Gyro Stabilizer." This paper describes a new type of stabilizing gyro mounted on top of a spindle by means of a universal joint, the spindle being kept in a vertical position by supporting it as a pendulum of which the bob is the driving motor. The paper also describes a new type of stabilized bomb sight in which only the cross wires of the sighting telescope are controlled by the gyro.

Part III, "The Testing and Use of Magnetic Compasses for Airplanes." Methods of tests and the difficulties in designing a satisfactory and reliable compass for aircraft use is considered in this paper.

Part IV, "Aircraft Compasses—Description and Classification." This paper contains a brief general treatment of the important features of construction of aircraft compasses and description of the principal types used. Mention is also made of several compasses now in the process of development.

Part V, "Turn Indicators." This report gives a brief history of the development of airplane turn indicators with detailed descriptions of all known types and makes. The results of laboratory and flight tests are given for the several available gyroscopic turn indicators.

Report No. 129, entitled "Power Plant Instruments." The report on power plant instruments is divided into five parts.

Part I, "Airplane Tachometers," gives a general discussion of the uses, principles, construction, and operation of airplane tachometers. Detailed description of all available instruments, both foreign and domestic, are given.

Part II, "Testing of Airplane Tachometers," a paper which describes methods of tests and the effect of various conditions encountered in airplane flight such as change of temperature, vibration, tilting, and reduced air pressure.

Part III, "Thermometers for Aircraft Engines." This paper describes the principal types of distance reading thermometers for aircraft engines, including an explanation of the physical principles involved in the functioning of the instruments and proper filling of the bulbs. Performance requirements and testing methods are given and a discussion of the source of error and results of tests.

Part IV, "Air Pressure and Oil Pressure Gauges." This paper gives methods of tests and calibration, also requirements of gauges of this type for the pressure measurement of the air pressure in gasoline tanks and the engine oil pressure on airplanes.

Part V, "Gasoline Depth Gauges and Flowmeters for Aircraft." The authors have described two types of gasoline gauges, the float type and the pressure type. Methods of testing and calibrating gasoline depth gauges are given. The Schroeder, R. A. E., and the Mark II Flowmeter are described.

Report No. 130, entitled "Oxygen Instruments." This report contains statements as to amount of oxygen required at different altitudes and the methods of storing oxygen. The two types of control apparatus—the compressed oxygen type and the liquid oxygen type—are described. Ten different instruments of the compressed type are described, as well as the foreign instruments of the liquid types. The performance and specifications and the results of laboratory tests on all representative types conclude this report.

Report No. 131, entitled "Aerial Navigation and Navigation Instruments." This paper outlines briefly the methods of aerial navigation which have been developed during the past few years, with a description of the different instruments used. Dead reckoning, the most universal method of aerial navigation, is first discussed. Then follows an outline of the principles of navigation by astronomical observation; a discussion of the practical use of natural horizons, such as sea, land, and cloud, in making extant observations; the use of artificial horizons, including the bubble, pendulum, and gyroscopic types. A description is given of the recent development of the radio direction finder and its application to navigation.

Report No. 132, entitled "Recent Developments and Outstanding Problems," by Franklin L. Hunt, Bureau of Standards. This report is Section VIII of a series of reports on aeronautic instruments (Technical Reports Nos. 125 to 132, inclusive) prepared by the Aeronautic Instruments Section of the Bureau of Standards under research authorizations formulated and recommended by the Subcommittee on Aerodynamics and approved by the National Advisory Committee for Aeronautics.

The preceding reports in this series have discussed in detail the various types of aeronautic instruments which have reached a state of practical development such that they have already found extensive use. It is the purpose of this paper to discuss briefly some of the more recent developments in the field of aeronautic instrument design and to suggest some of the outstanding problems awaiting solution. The different types of instruments will be considered as far as possible in the order in which they are discussed in the preceding papers.

LIST OF TECHNICAL NOTES ISSUED BY NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS DURING THE PAST YEAR.

No. 22. The Photographic Recording of Small Motions. By F. H. Norton, N. A. C. A.
23. Horizontal Buoyancy in Wind Tunnels. By A. F. Zahm, Bureau C. & R., Navy Department.
24. Development of the Inflow Theory of the Propeller. By A. Betz. Résumé translated from the German by Paris Office, N. A. C. A.
26. A Variable Speed Fan Dynamometer. By Karl D. Wood, Bureau of Standards.
27. Instrument for Measuring Engine Clearance Volumes. By S. W. Sparrow, Bureau of Standards.
28. Loads and Calculations of Army Airplanes. By Stelmachowski. Translated from Technische Berichte, Vol. III, No. 6, by Office of Naval Intelligence, U. S. Navy Department.
29. Progress made in the Construction of Giant Airplanes in Germany during the War. By A. Baumann. Résumé translated from the German by Paris Office, N. A. C. A.
30. Design of Recording Wind Tunnel Balances. By F. H. Norton, N. A. C. A.
31. Crippling Strength on Axially Loaded Rods. By Fr. Natalis. Translated from Technische Berichte, Vol. III, No. 6, by Prof. Pawlowski, University of Michigan.
32. Causes of Cracking of Ignition Cable. By F. B. Silsbee, Bureau of Standards.
33. The Effect of the Nature of Surfaces on Resistance, as Tested in Struts. By C. Wieselsberger. Translated from Zeitschrift fur Flugtechnik und Motorluftschiffahrt, Feb. 28, 1920, by Paris Office, N. A. C. A.
34. The 300 H. P. Aviation Engine. By Dr. A. Heller. Translated from Zeitschrift des Vereines Deutscher Ingenieure, by Paris Office, N. A. C. A.
35. The Optical Wing Aligning Device of the Langley Field Tunnel. By F. H. Norton, N. A. C. A.

No. 36. N. A. C. A. Langley Field Wind Tunnel Apparatus. The Tilting Manometer. By F. H. Norton, N. A. C. A.

37. The Determination of the Effective Resistance of a Spindle Supporting a Model Aerofoil. By W. E. Davidson and D. L. Bacon, N. A. C. A.

38. Measurements of Rudder Moments on an Airplane During Flight. By V. Heidelberg. Translated from Zeitschrift fur Flugtechnik und Motorluftschiffahrt, Vols. 21 and 22, by Paris Office, N. A. C. A.

39. High Thermal Efficiency in Airplane Service. By S. W. Sparrow, Bureau of Standards.

40. Effect of the Reversal of Air Flow upon the Discharge Coefficient of Durley Orifices. By Marsden Ware, N. A. C. A.

41. Influence of Span and Load per Square Meter on the Air Forces of the Supporting Surfaces. By A. Betz. Translated from Technische Berichte, Vol. 1, Sec. 4, by Lt. W. S. Diehl, Bureau C. & R., Navy Department.

42. The Determination of Downwash. By Lt. Walter S. Diehl, Bureau C. & R., Navy Department.

43. Note on the Resistance of Polished Cylinders (and cylindrical Wires) with Generatrices Perpendicular to the Airstream, by A. Toussaint. Translated from the French by Paris Office, N. A. C. A.

44. On the Resistance of Spheres and Ellipsoids in Wind Tunnels. By D. P. Riabouchinsky. Translated from Bulletin of the Aerodynamic Institute of Koutchino, by Paris Office, N. A. C. A.

45. Extract from a Report on the Resistance of Spheres of Small Diameter in an Airstream of High Velocity. By Capt. Toussaint and Lt. Hayer. Translated from the French by Paris Office, N. A. C. A.

46. Theory of the Ideal Windmill. By Wilhelm Hoff. Translated from the German by Paris Office, N. A. C. A.

47. Recent European Developments in Helicopters. Prepared by Paris Office, N. A. C. A.

48. Airplane Superchargers. By W. G. Noack. Translated from Zeitschrift des Vereines Deutscher Ingenieure, 1919, by Office of Naval Intelligence, Navy Department.

49. On the Resistance of the Air at High Speeds and on the Automatic Rotation of Projectiles. By D. Riabouchinsky. Translated from the French by Paris Office, N. A. C. A.

50. The Gordon Bennett Airplane Cup, 1920. By W. Margoulis, N. A. C. A.

51. Airplane Balance. By L. Huguet. Translated from "La Vie Technique and Industrielle," 1920, by Paris Office, N. A. C. A.

52. A New Method of Testing Models in Wind Tunnels. By W. Margoulis, N. A. C. A.

53. Similitude Tests on Wing Sections. By H. Kumbruch. Translated from the German by D. L. Bacon, N. A. C. A.

54. The Factors that Determine the Minimum Speed of an Airplane. By F. H. Norton, N. A. C. A.

55. Airplane Crashes; Engine Trouble. A Possible Explanation. By S. W. Sparrow, Bureau of Standards.

56. The Development of German Army Airplanes During the War. By Wilhelm Hoff. Translated from Zeitschrift des Vereines Deutscher Ingenieure, 1920. By office of Naval Intelligence, Navy Department.

RESEARCH PROGRAM AND ESTIMATES.

For the year 1923 the National Advisory Committee for Aeronautics has planned a program of research which the committee considers vital to progress in aviation in the United States and is still in keeping with the economical policies now affecting the expenditure of governmental funds. The program has been recommended by the subcommittees on aerodynamics, power plants for aircraft, and materials for aircraft, and has been approved by the executive committee.

Aerodynamical research.—The use of the new compressed-air wind tunnel will make possible the determination of forces on an airplane and the determination of the interference effects of the structural members. The information obtained can be used directly by the designer, and the determination of the interference effects may have an important effect on the character of design.

The free-flight testing program provides for the determination of pressure distribution and stresses in airplanes at high speed and when violently maneuvered. For this particular research it may be necessary to construct a special airplane having double the usual factor of safety.

Statical and dynamical stability are to be investigated for various modifications of standard types of airplanes, with a view toward finding the relation between these characteristics and the variable factors in a given design. This investigation will attempt to find the relation between model tests and full-scale performance in such a manner that the designer will be enabled to interpret model-test results with confidence.

The full-scale investigation is concerned also with controllability. The effectiveness of control surfaces with systematic modification is to be given special study for the purpose of finding not only the effects of certain changes in design but also the amount of control required in any given case.

All of the full-scale work is planned with the view of making the results general and broad in their scope. This will be secured by repeating tests on different types of airplanes with automatic recording instruments.

The tests of aerofoils suspended from a balance placed in an airplane and tested in free flight shows promise. So far a model wing section with a 1-foot chord and a length of 6 feet has given such results that the work is being continued, and it is hoped to test a full-sized airplane wing suspended from a Martin bomber.

Preliminary tests have been made, and a satisfactory pressure pad has been developed for use in determining pressure distribution on an airship in flight. A special recording multiple manometer for these tests is now completed, and the results obtained will be of great value to the designer.

The research program in aerofoils provides for the continued study of designs and methods of construction that will make it possible to increase the lift characteristics of aerofoils. This problem is of great importance in providing for a lower landing speed and a quicker take-off. From a commercial and also a military point of view, the high lift wing will greatly increase the useful load carried or the greater flying range of the aircraft.

The committee asks for the sum of $141,134 to carry out research work in connection with aerodynamics.

Materials research.—The progress made during the past year in the development of all-metal aircraft has not been altogether satisfactory. The difficulty seems to be that as yet we have not developed suitable and economical methods of producing and fabricating aluminum alloys. The methods so far developed have been limited to the construction of the *ZR-I* and the Stout all-metal airplane. The Bureau of Standards is equipped and expects to conduct a series of investigations on the rolling and shaping of duralumin for aircraft construction. The heat treatment of the material will also be carefully studied in connection with the results of cold working.

The fatigue tests are to be continued to obtain reliable data for the designer, and vibration tests are to be made on various types of airplanes to determine some idea of the character of vibrations to be expected.

One of the most serious drawbacks of the present type of airplane is the cost of manufacture and the short life of the structure. Even in quantity production the cost is excessive, but if the materials used in the construction consisted entirely of metal, the parts would lend themselves better to quantity production, longer life would be assured, and storage conditions would be improved. Research on both steel and light alloys for aircraft will be carried on and an effort made to further interest manufacturers in the production of materials especially suitable for aircraft purposes.

Woods, glues, and protective coatings are not entirely satisfactory, and the cost of these materials for aircraft construction is excessively high. Research will be continued to produce a substitute for goldbeaters' skin, the present airplane dope, and new methods of wing rib and spar construction, especially in connection with the further development of plywood structures.

Aircraft power plants research.—The outstanding problem considered in connection with power plants for aircraft is the developing of a reliable engine that will use a low-grade fuel or a fuel with a much lower flash point than our present gasoline. With an engine of this type the fire hazard in aircraft would be greatly minimized and the reliability greatly increased by the elimination of the ignition system, the carburetor, and other accessories that are now responsible in a large part for engine failures. The progress made so far on this investigation is most encouraging and it is expected that within the year a successful experimental engine of this type will be produced. The engine will weigh more than the present type of aviation engine, but will lend itself to cheaper construction as the pressures and forces to be considered are about the same as now exist in aircraft engines.

The various types of superchargers will be investigated; five different types are to be tested. The use of the new altitude chamber at the Bureau of Standards will permit of the accurate determination of the characteristics of supercharged engines. Provision has been made so as to make it possible to test the exhaust turbine type supercharger in the altitude chamber and simulate conditions experienced at high altitude. The Moss type supercharger developed at McCook Field has been most successful, but it is hoped that a type considerably lighter and less complicated will result from the investigations during the coming year.

The radiator investigation will be continued especially with a view of determining from free flight and laboratory tests a type of radiator design giving the least air resistance and also providing for ease of installation and repair.

Research is planned for the further study of air-cooled cylinders, as it is realized that for certain types of aircraft the air-cooled engine in units up to 250 horsepower has a decided advantage.

The most severe limitation now placed on the further development of high-powered lightweight engine is due to preignition or erratic burning occurring when our present grades of gasoline are used. A study of the fuel problem will be carried on in connection with the study of the phenomena of combustion in an effort to control, if possible, the rate of combustion, which has been, so far, beyond control.

The estimate of the committee to cover the necessary power plant research for the fiscal year 1923 is $123,866.

Summary.—The committee's estimates for the prosecution of the programs of aerodynamical research, materials research, and aeronautic power plant research, as outlined above, total $265,000. To this should be added, under the committee on publications and intelligence, the work of the Office of Aeronautical Intelligence, in the collection, classification, and dissemination of scientific and technical reports and data on aeronautics, requiring the sum of $48,300, and for the general administration of the Washington office with its present personnel, the sum of $27,700, making the total estimates for the fiscal year 1923, $341,000. The appropriation for the fiscal year 1921 was $200,000, and for the present fiscal year the appropriation is $200,000. The continuous prosecution of a well-organized plan of scientific research is an essential factor in the development of the science of aeronautics, and the increased estimates of the committee for the fiscal year 1923 are made necessary by the increasing relative importance of scientific research in the general development of aeronautics.

FINANCIAL REPORT.

The appropriation for the National Advisory Committee for Aeronautics for the fiscal year 1921, as carried in the sundry civil appropriation act approved June 5, 1920, was $200,000 under which the committee reports expenditures and obligations during the year amounting to $199,959.21, itemized as follows:

Salaries (including engineering staff)	$66, 881. 22
Wages	33, 955. 04
Equipment	9, 691. 73
Supplies	27, 783. 99
Transportation and communication	912. 58
Travel	6, 081. 65
Special investigations and reports	46, 725. 00
Construction of buildings	7, 928. 00
Total	199, 959. 21

CONCLUSION.

As has been stated before, the primary function of the committee is to pursue scientific investigations in aeronautics. This is necessarily the most important field in the whole subject of aviation, if fundamental progress is to be made. When the results of physical and mathematical study are known, and not until then, better airplanes or other aircraft can be designed. Without these scientific results progress will be empirical and uncertain. No other activity in aviation at the present time in this country so much needs intelligent governmental support.

Respectfully submitted.

National Advisory Committee for Aeronautics,
Joseph S. Ames, *Chairman Executive Committee.*